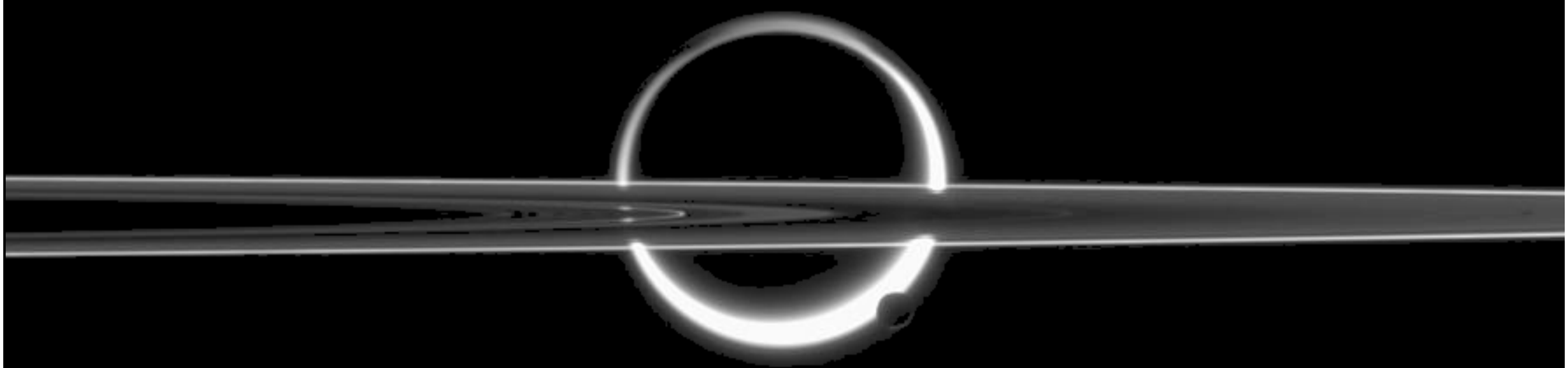
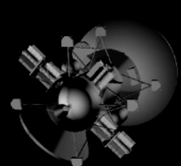
Titan Saturn System Mission
In Situ Science and Instruments





Presentation at OPFM Instrument Workshop

Presented by Athena Coustenis

June 3, 2008

European Space Agency, ESA/ESTEC, Noordwijk

Athena Coustenis

Laboratoire d'Etudes Spatiales et d'Instrumentation en Astrophysique (LESIA)
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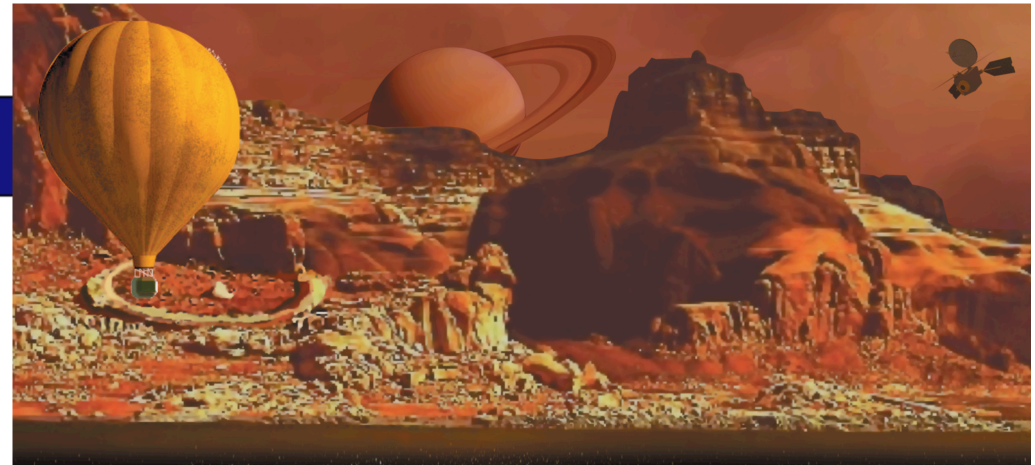
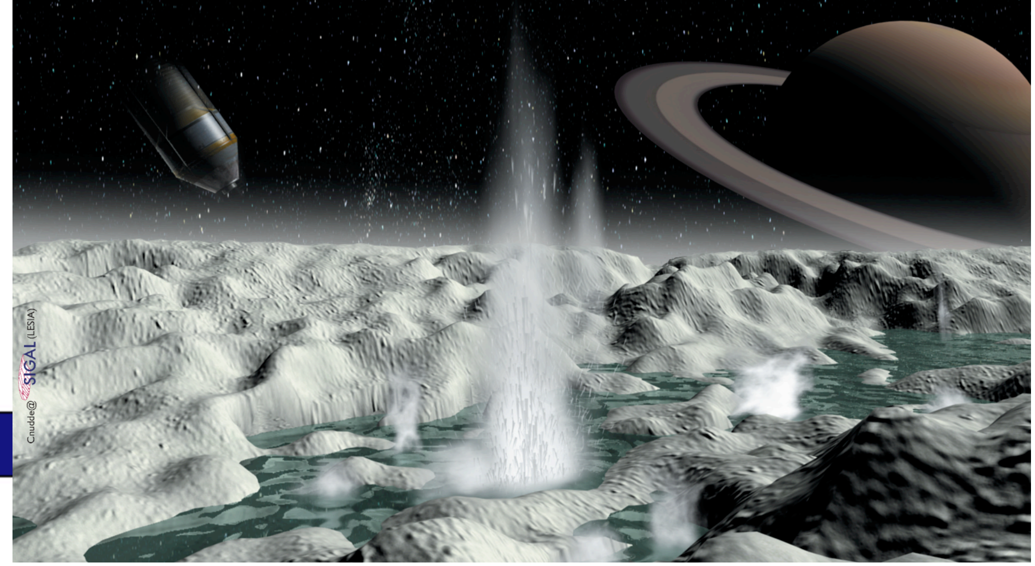


TSSM : Titan/Saturn System Mission (ex TandEM + Titan Explorer)

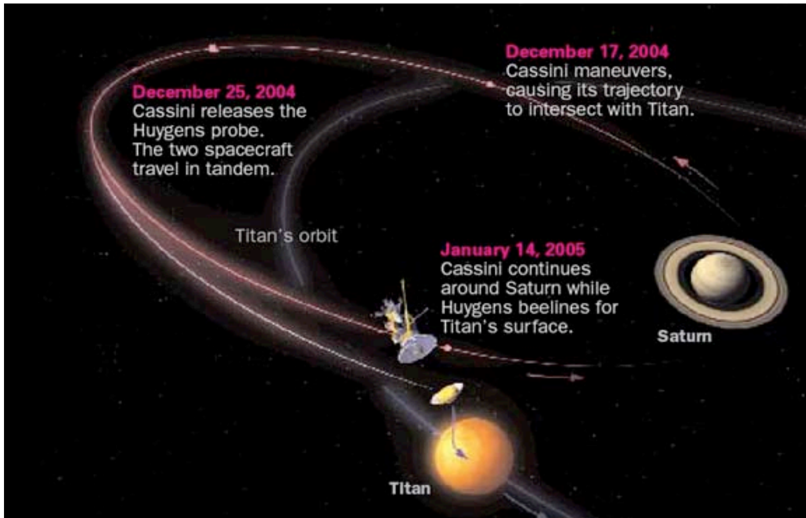
In situ Element Science and Instruments

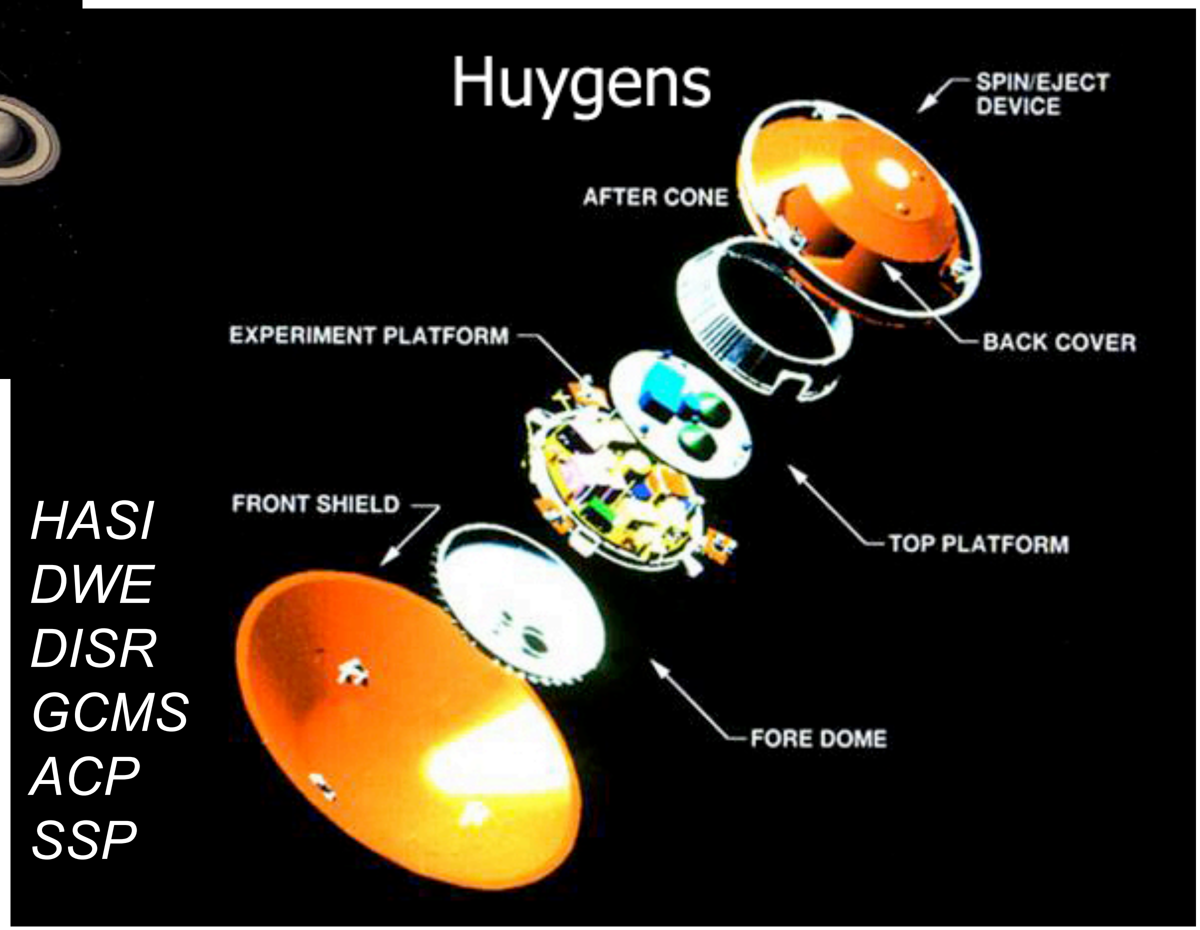


<u>*TSSM JSDT*</u>
Chairs: J. Lunine, J-P. Lebreton
Lead Scientists: A. Coustenis, D. Matson, C. Hansen
L. Bruzzone, M-T. Capria, J. Castillo-Rogez,
A. Coates, M. Dougherty, A. Ingersoll, R. Jaumann,
W. Kurth, M-L. Lara, C. McKay, R. Lopes, R. Lorenz,
I. Müller-Wodarg, O. Prieto-Ballesteros, F. Raulin,
A. Simon-Miller, E. Sittler, J. Soderblom, F. Sohl,
C. Sotin, D. Stevenson, E. Stofan, G. Tobie,
T. Tokano, P. Tortora, E. Turtle, H. Waite

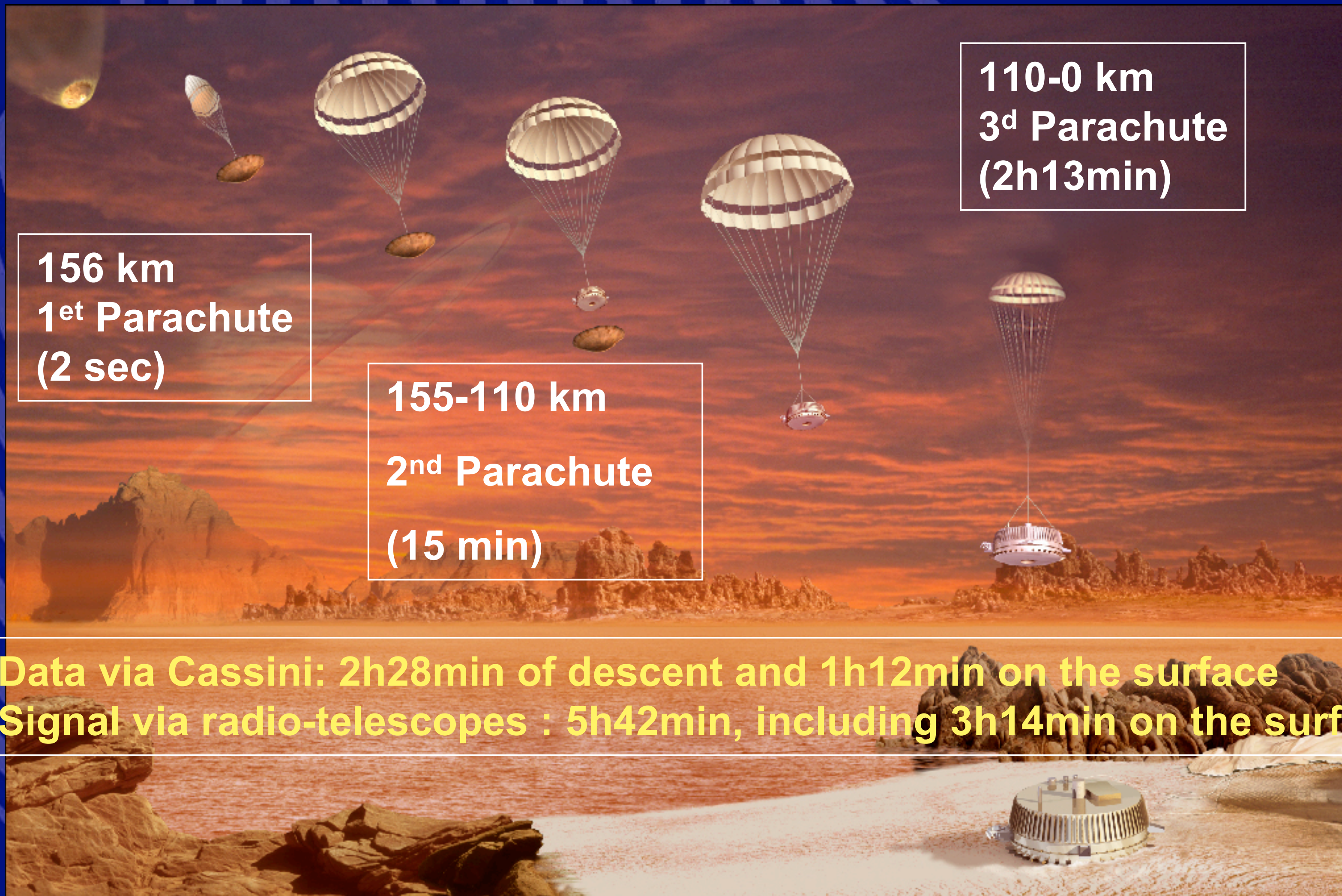
Thanks to CNES

Huygens : the descent module





Huygens Descent and Landing Overview



Data via Cassini: 2h28min of descent and 1h12min on the surface
Signal via radio-telescopes : 5h42min, including 3h14min on the surface

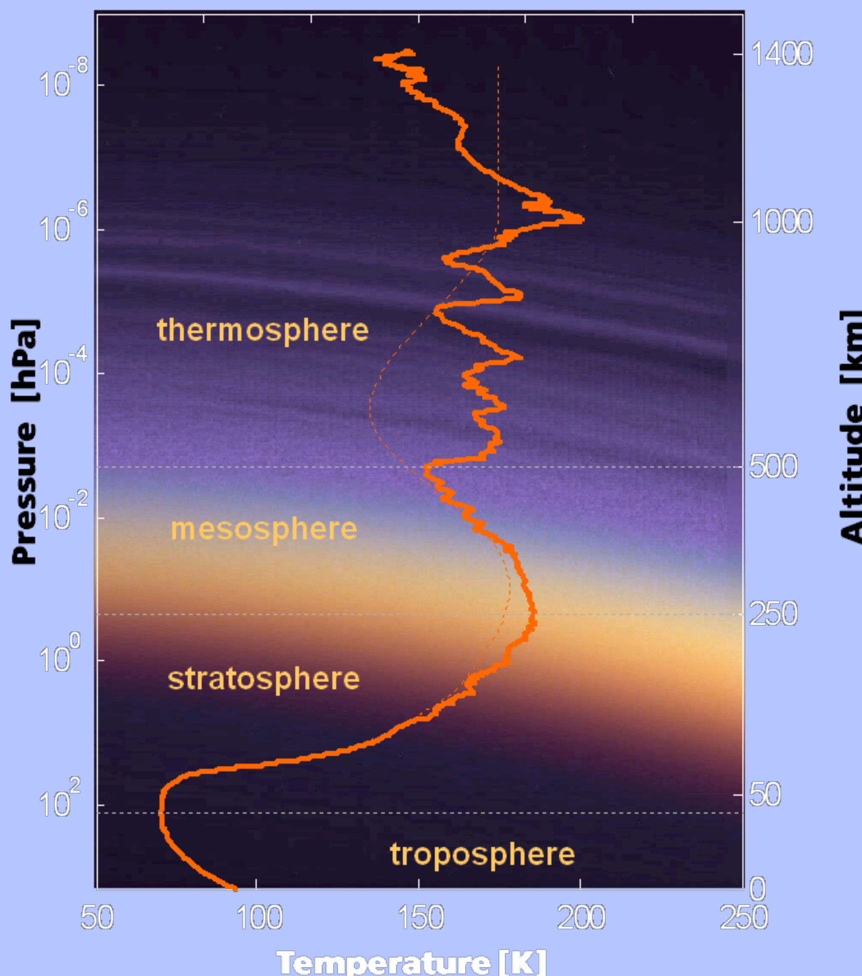
esa

Titan's atmospheric structure

- In the **upper atmosphere** density & temperature higher than expected. Wave-like nature of thermal profile => atmosphere is highly stratified and variable in time.
  Stratopause 180 K at 250 km

- **Lower stratosphere** & **tropopause**: very good agreement with Voyager 1 temperature.
  Tropopause 71 K at 44 km

- At **surface**:
  Temperature 93.4 K
  Pressure ~1.5 bar



Fulchignoni et al., 2005

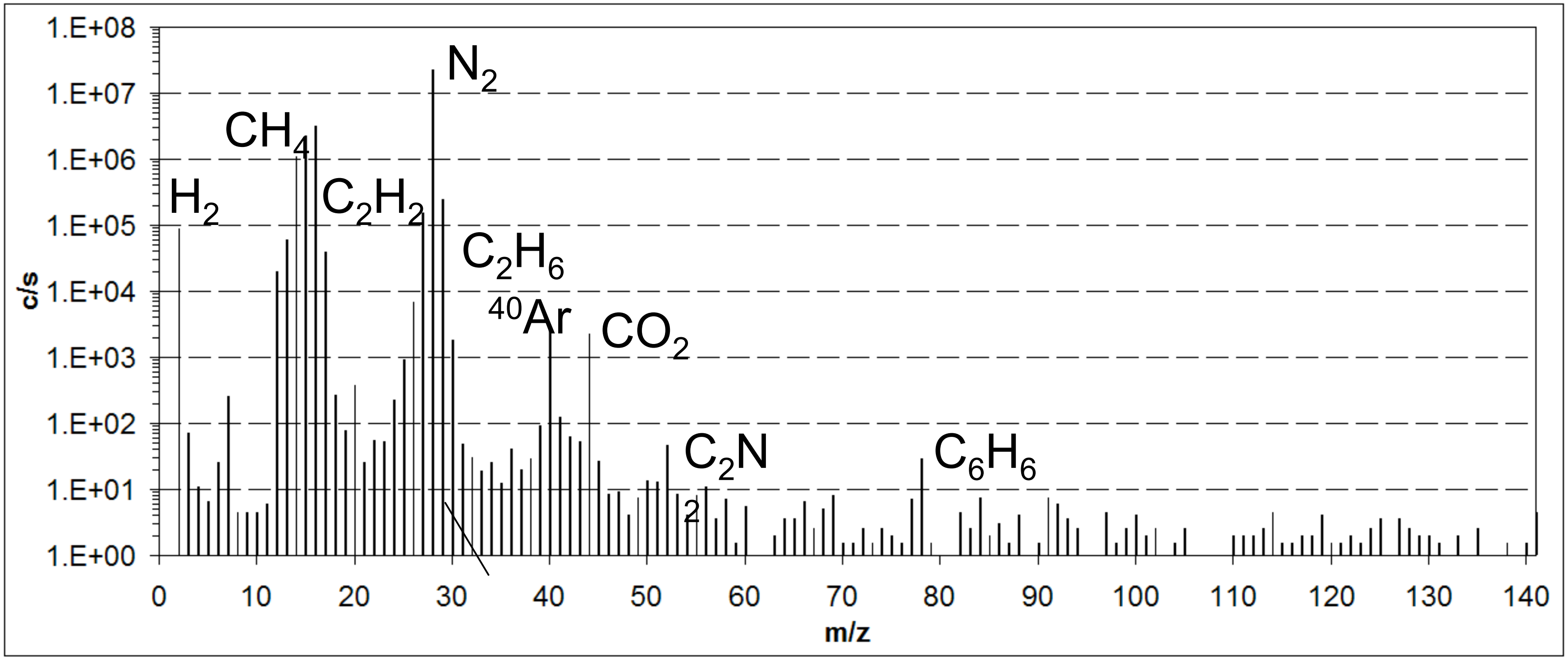
PRE-DECISIONAL DRAFT— For planning and discussion purposes only

Surface Observations with the GCMS

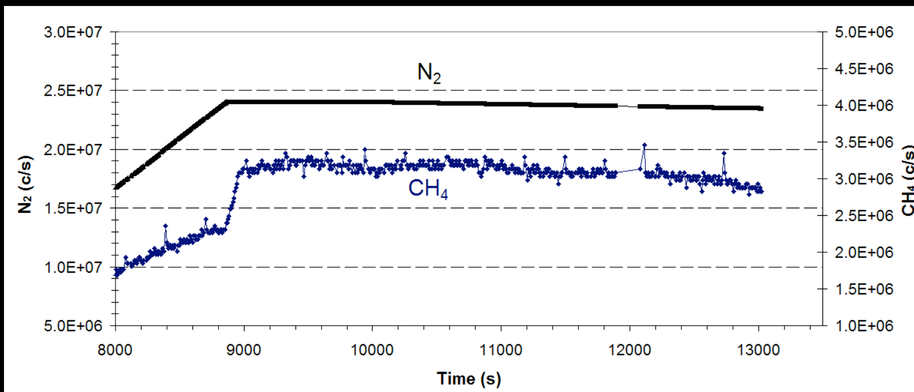
(Niemann et al., Nature, 438, 779-784, 2005)

Detection of various organic compounds on the surface:

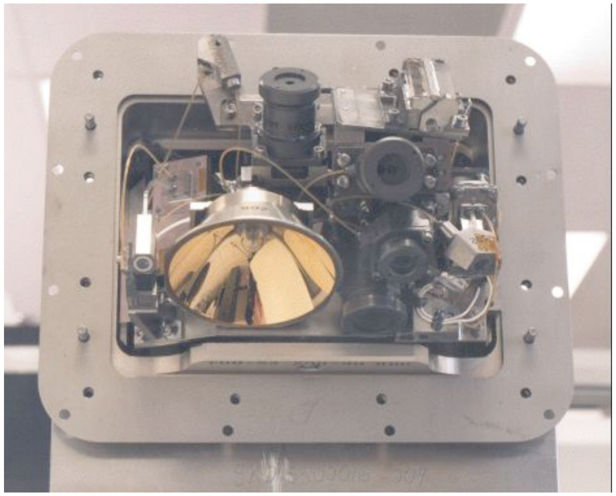
Ethane, acetylene, cyanogen, benzene and in addition carbon dioxide.



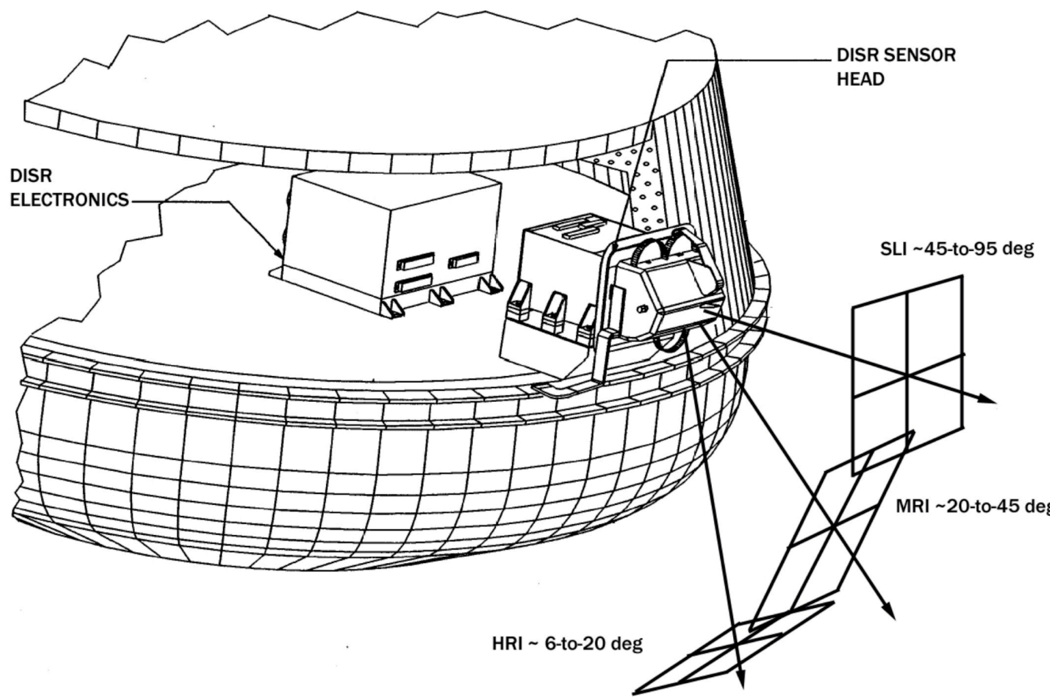
Methane evaporated from the surface after warming from the heated sample inlet as observed by an increase of the methane signal after impact. A moist area with liquid methane in the near sub-surface is indicated.

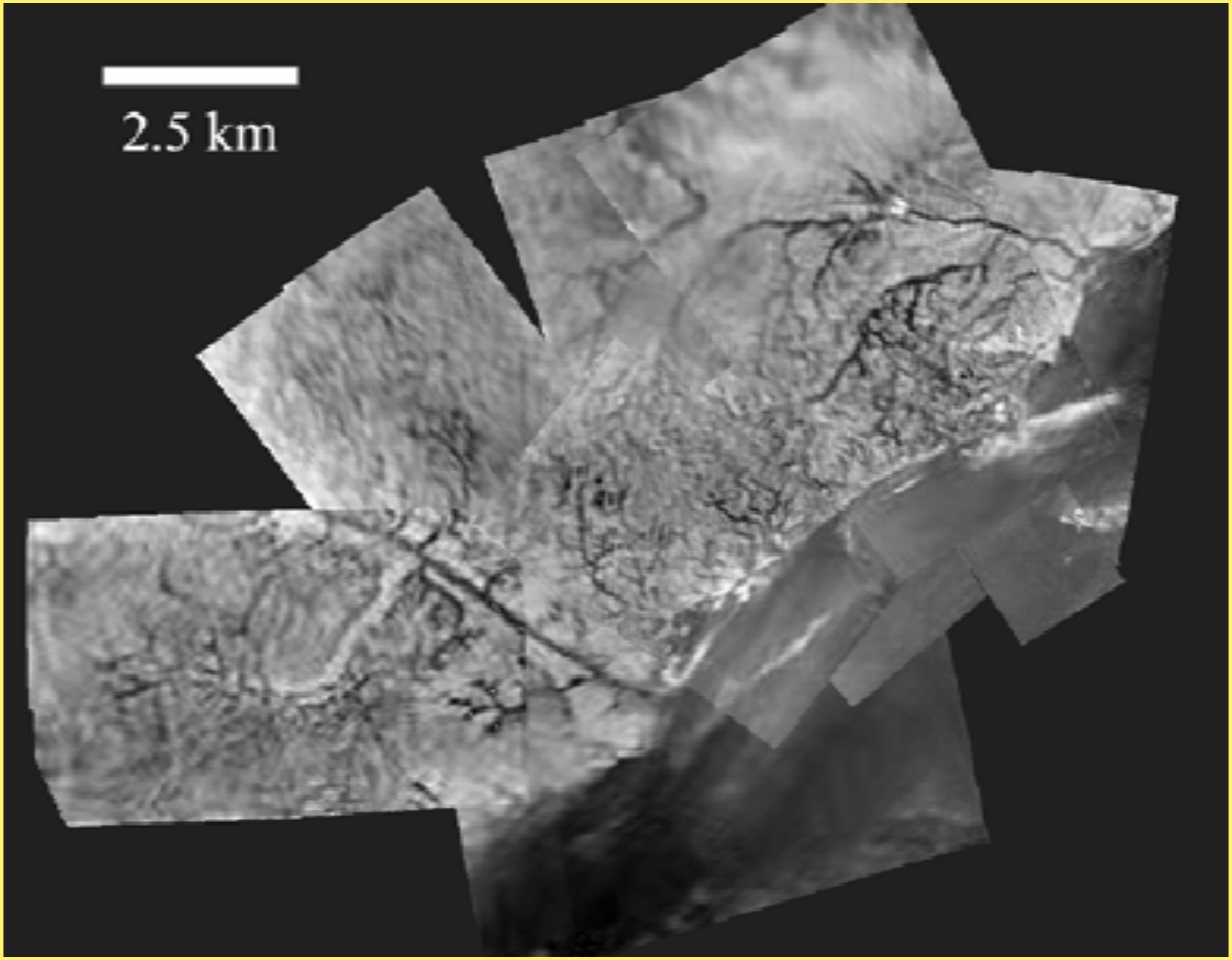


The DISR instrument

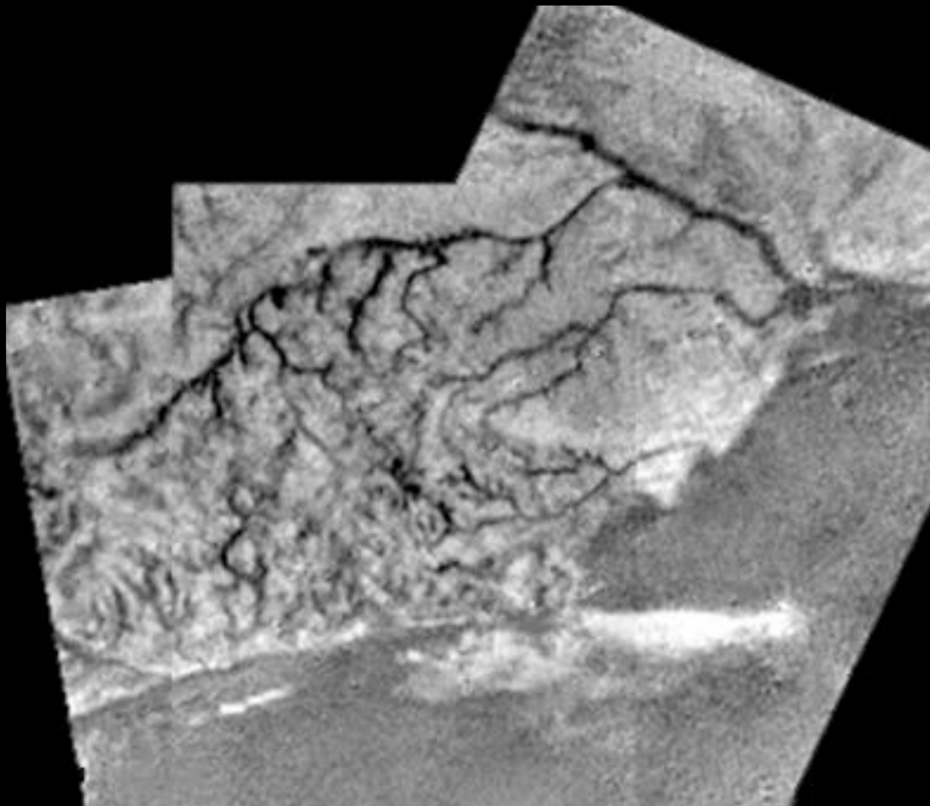


DISR Imagers Approximate Fields-of-View

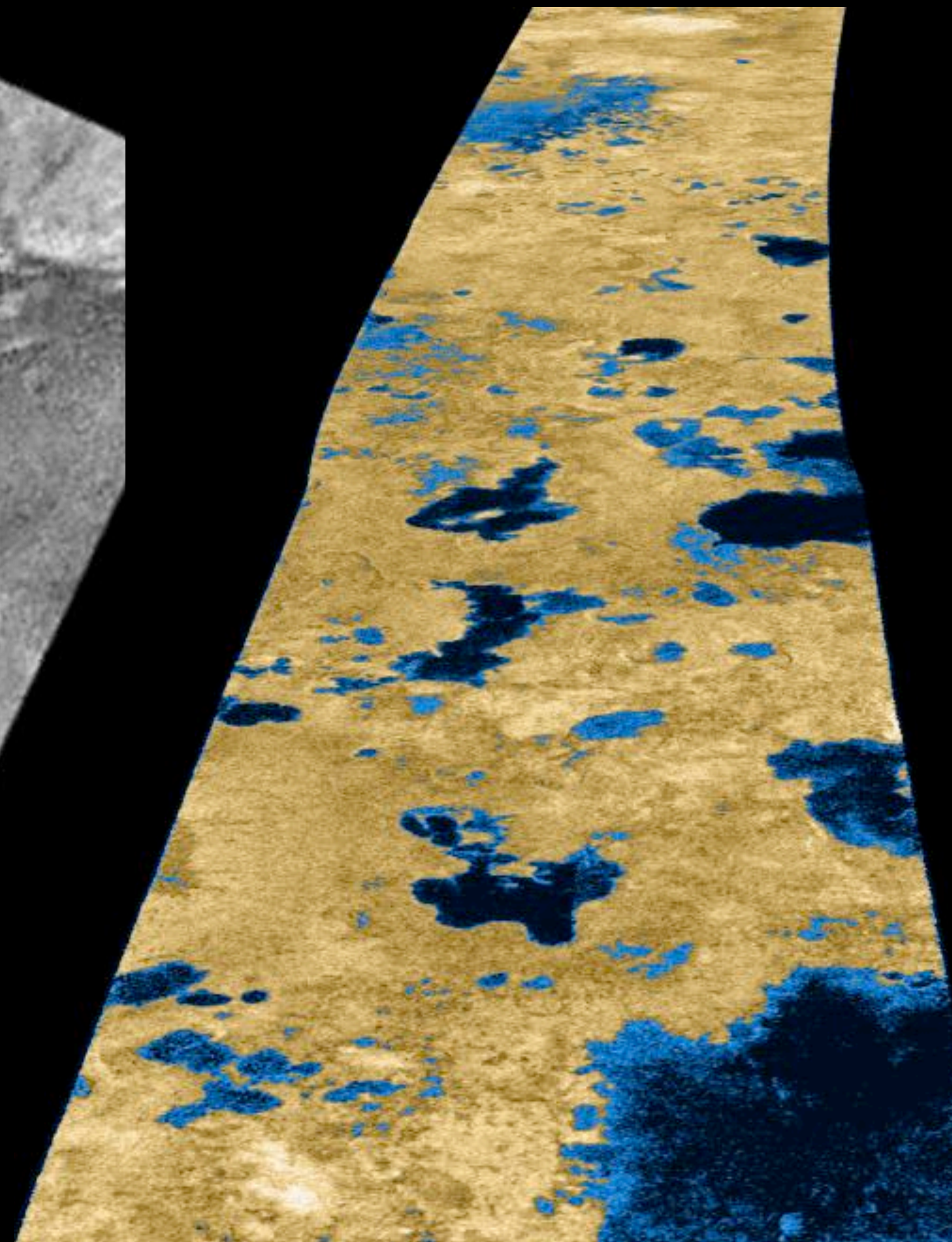




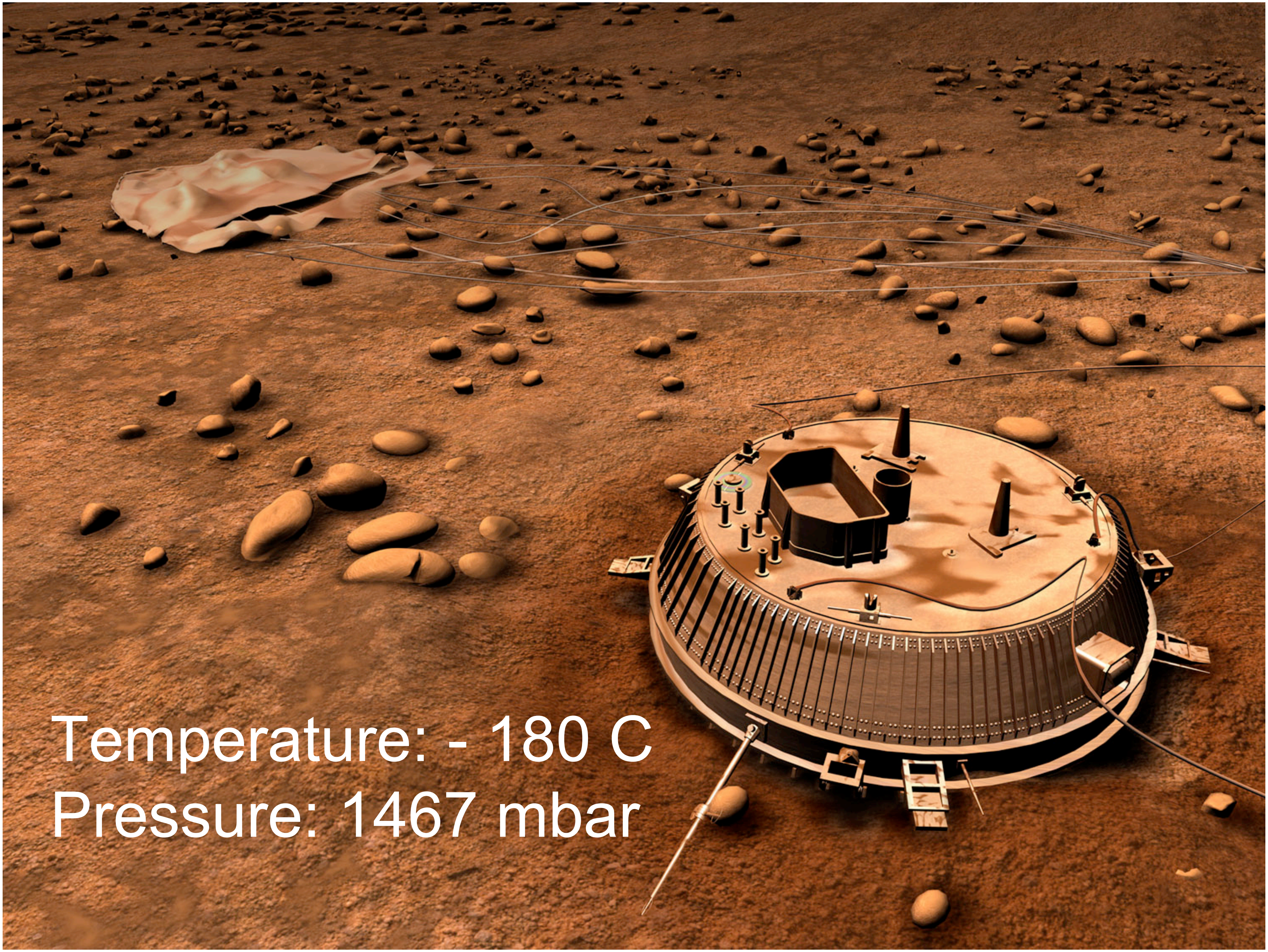
Panoramic mosaic projected from 6.5 km showing an expanded view of the highlands and bright-dark interface



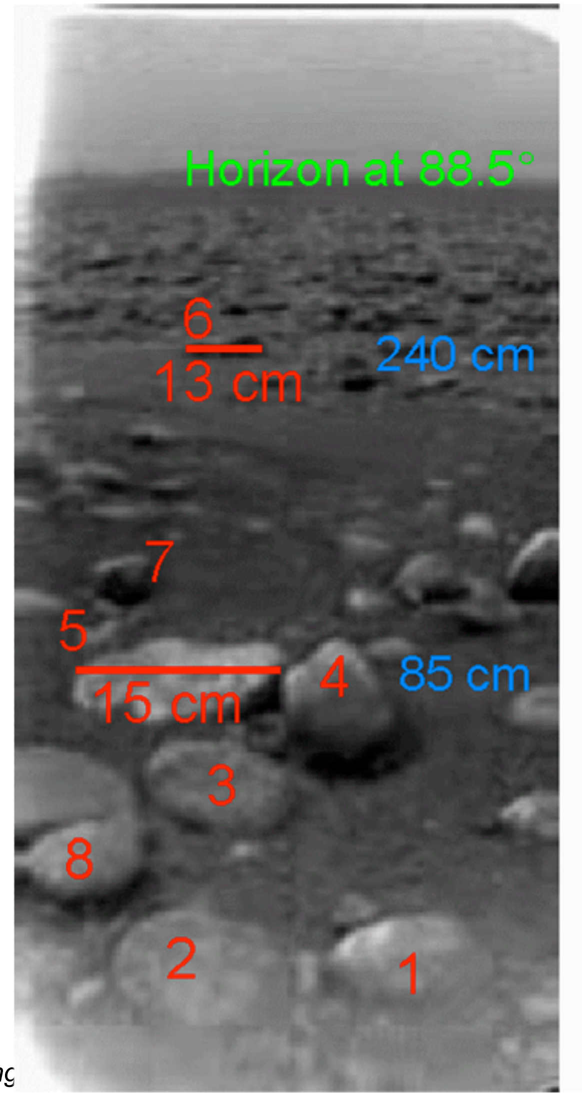
Huygens DISR alt ~4 km



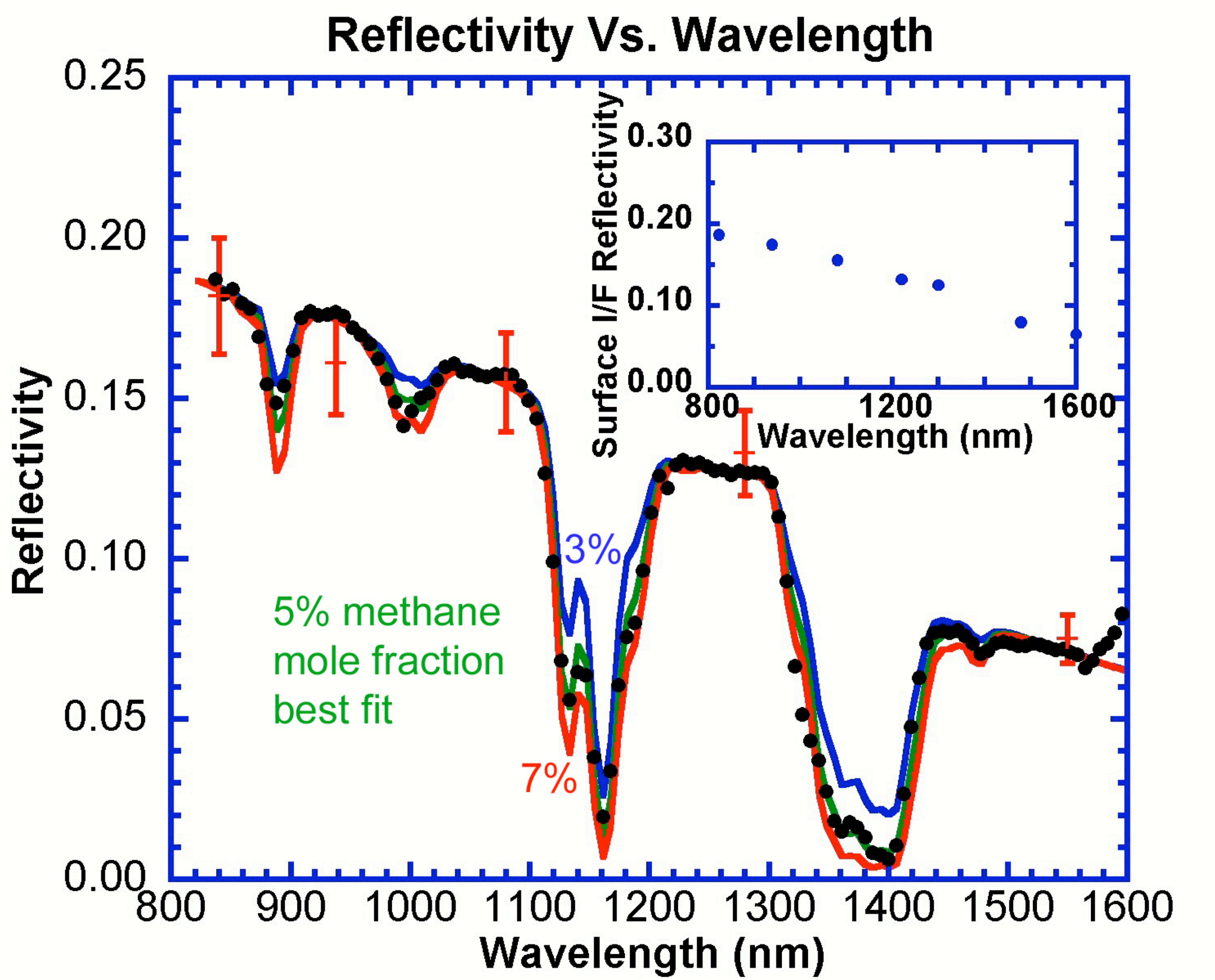
Cassini radar


Temperature: - 180 C
Pressure: 1467 mbar

Pebbles on Titan



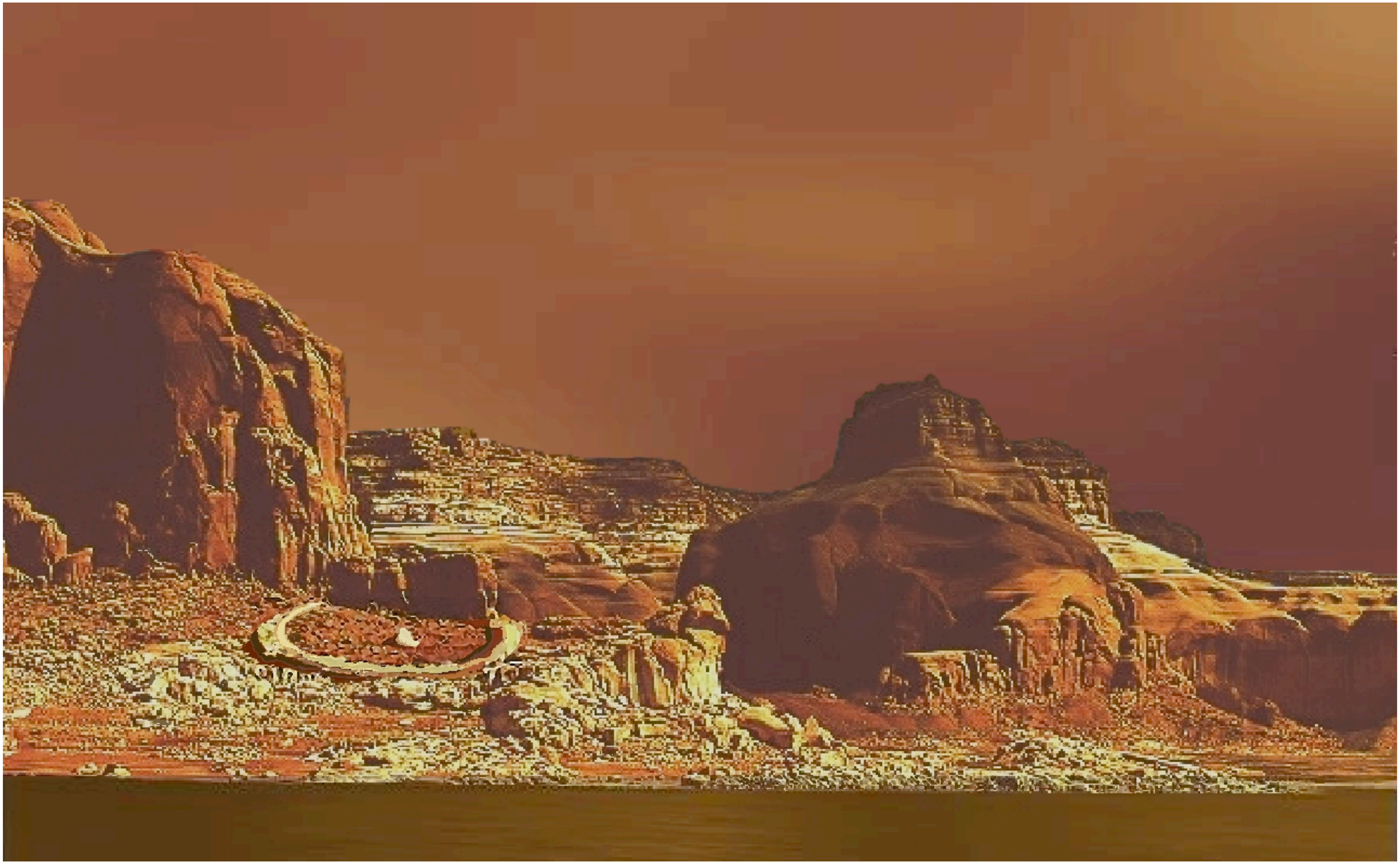
DLIS spectrum at 20 m



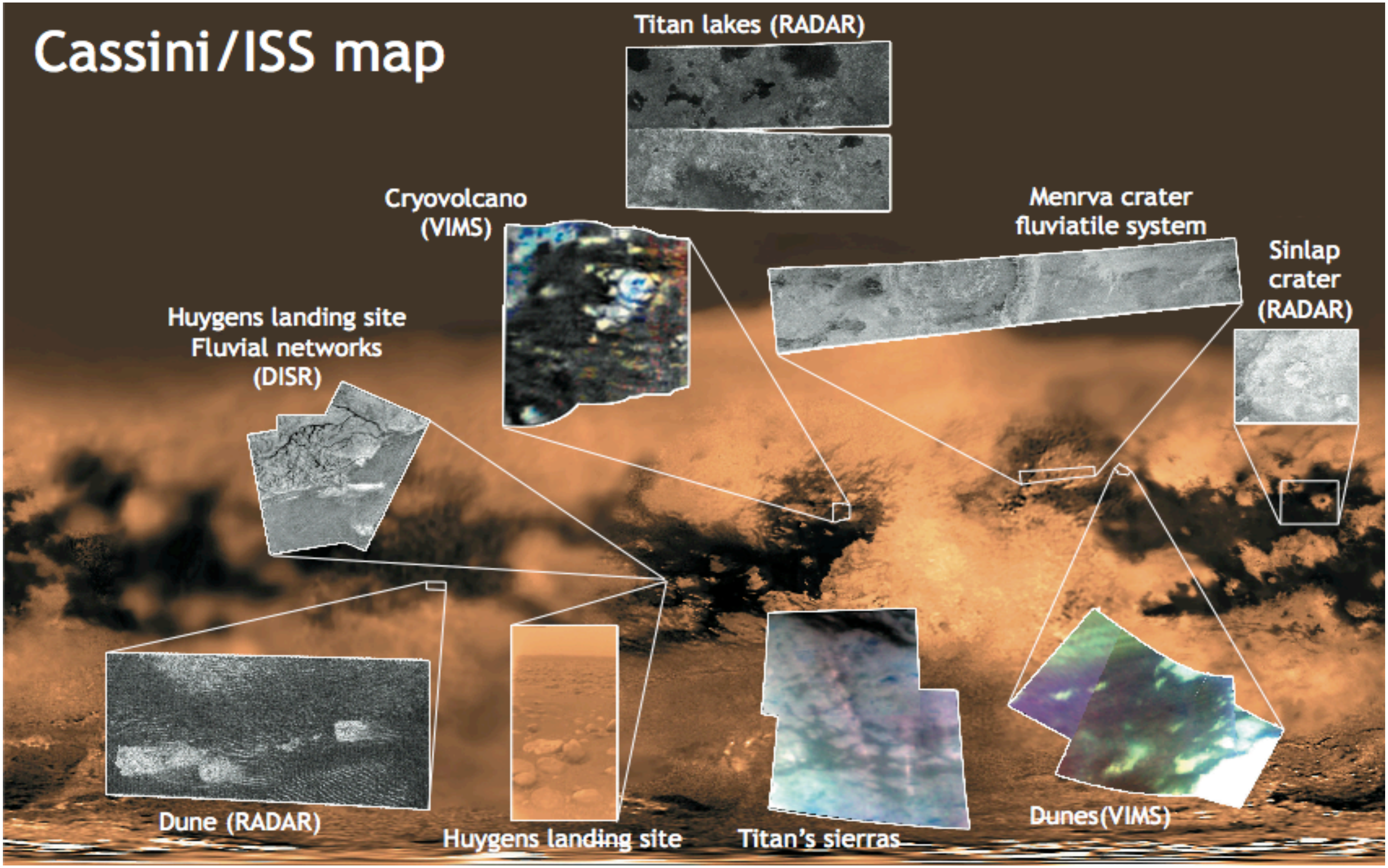
Methane :
about 5%
at the
surface

Surface :
Dark
material
Probable
water ice
absorption

DISR-based reconstructed view of Titan landscape from the Huygens landing site

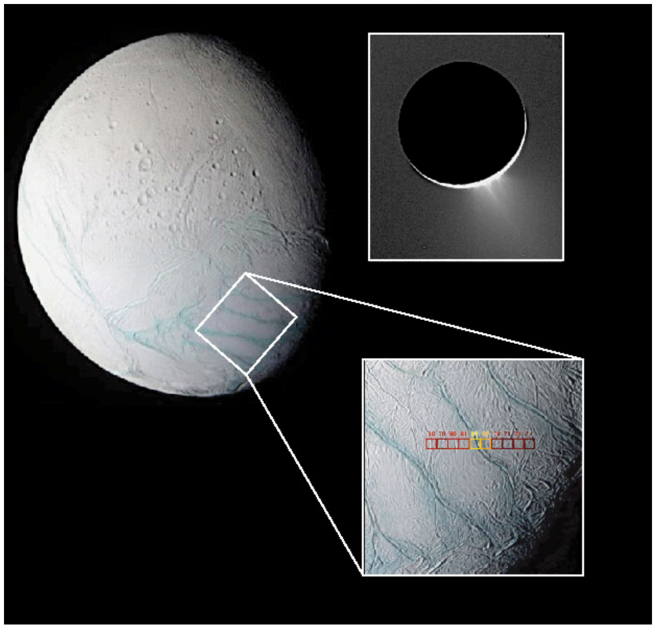


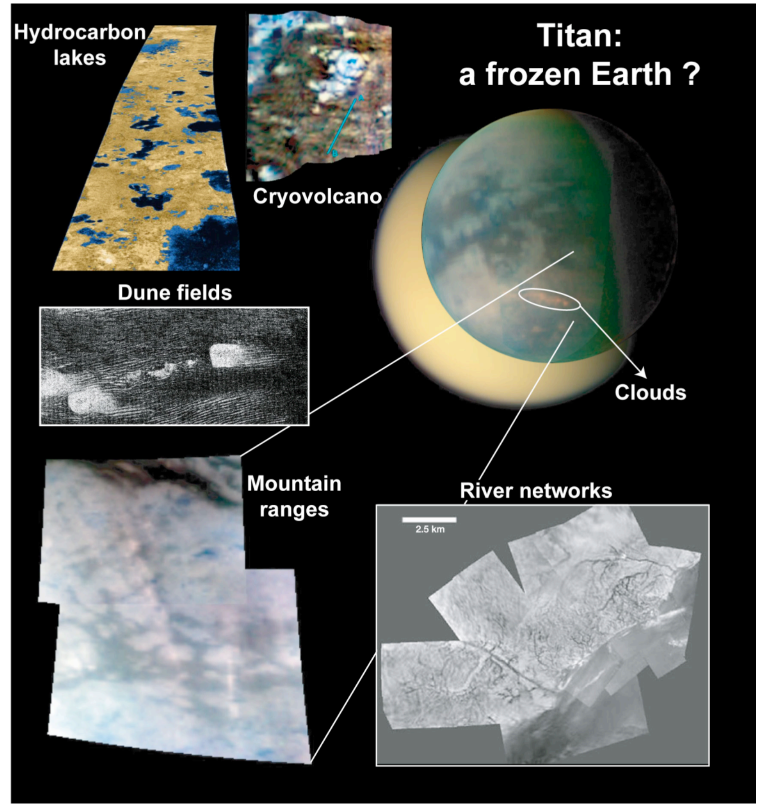
Titan : Cassini-Huygens images of Titan's surface



Why Titan and Enceladus after Cassini-Huygens?

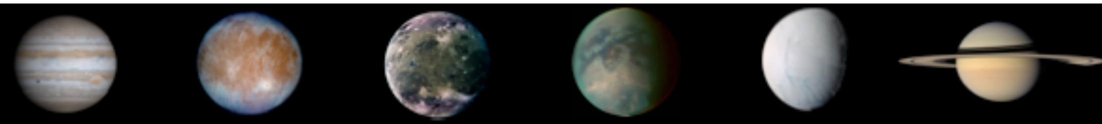
The revelations of Cassini-Huygens (2004-2010)





Even when the extended mission is taken into account, Cassini-Huygens will have provided us with

- a few Enceladus flybys
- about 60 hours of Titan flybys closer than 10,000 km;
- ~35% of high-resolution RADAR/SAR coverage (1-2 km) of Titan and only a few % of near-IR surface mapping at 2-km resolution ;
- 14 Titan radio-occultations and a few hundred hours of far/mid IR observations;
- 70 Titan magnetic field observations; 50 ionospheric profiles



Why a new mission?

✔ Cassini-Huygens did a great job in revealing the basic natures of Titan and Enceladus as geologically active planetary objects with atmospheres and of high astrobiological interest.

☛ But it raised many fundamental questions and opened the path for a mandatory exploration that will give us the answers.

How? With TSSM !

- ✢ with a Titan-dedicated orbiter for complete mapping of the surface and exploration of as yet unknown parts of the atmosphere
- ✢ with a full multi-site in situ exploration of Titan with balloon and probes
- ✢ with extensive in situ exploration of Enceladus
- ✢ with a host of new instruments adapted to this kind of exploration
- ✢ at a later season so as to study Titan in the 2026-2031 timeframe, at a season complementary to that observed by Cassini

A long-lived multi-element architecture enables powerful synergistic science via simultaneous measurements at different places or scales. We will thus be able to address questions that have not been in Cassini-Huygens' objectives: surface, interior, astrobiology, organic content, etc

In situ with TSSM :

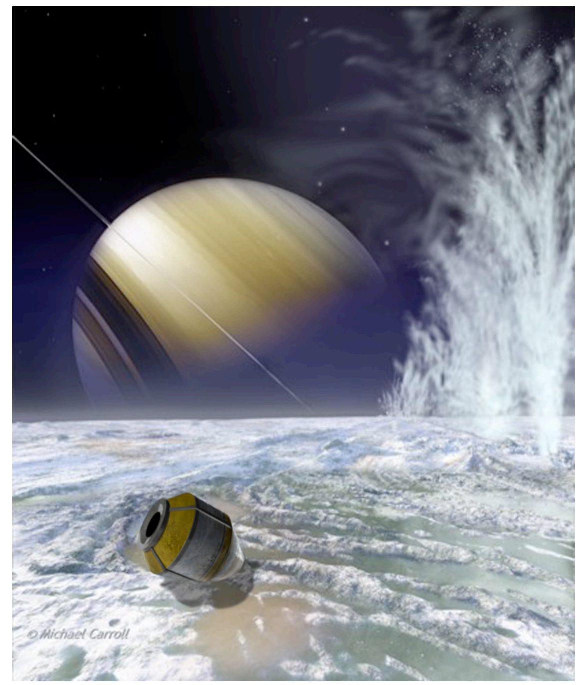
A multi-element Post-Cassini-Huygens exploration of Titan

Titan as a system

Origin, evolution and interior

Astrobiological potential

Enceladus plumes & subsurface



http://www.lesia.obspm.fr/cosmicvision/tandem/

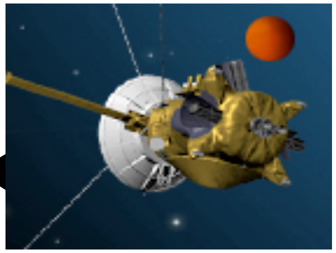
Preferred mission architecture

A possible option is a combination of

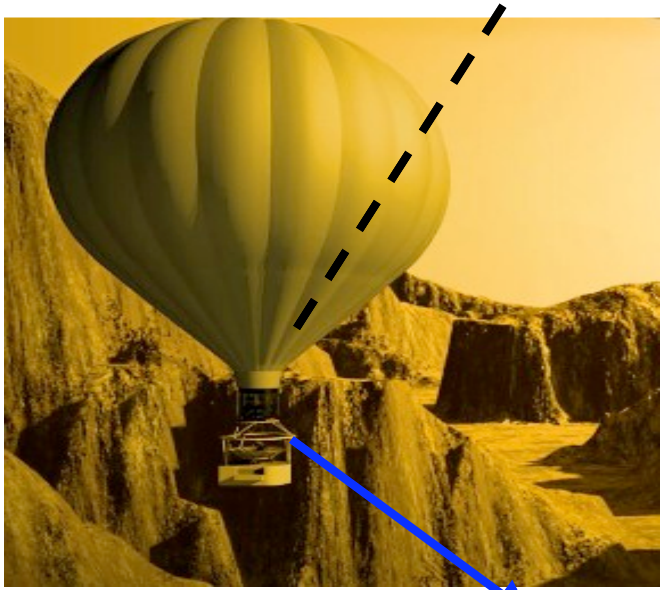
- An orbiter (Titan+Enceladus)
- A Balloon/Montgolfière on Titan

and mini-probes with surface packages

  - Penetrators/Landers for Enceladus ?



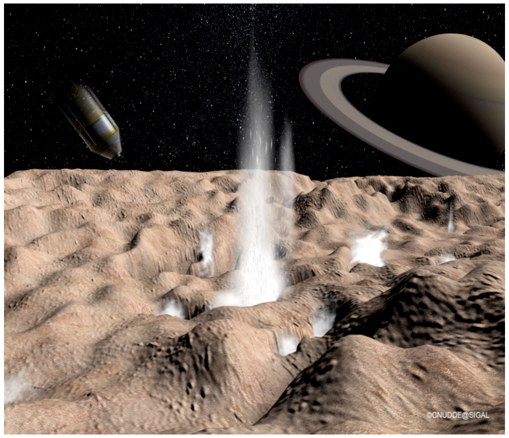
Orbiter will be used also for relay



Balloon and lander(s) on Titan Montgolfière will float within a few km above the surface with altitude control

Lander(s) with surface package

Sample acquisition with a tether and drill



Possible release of penetrators on Enceladus?

Focus of TSSM in situ science objectives

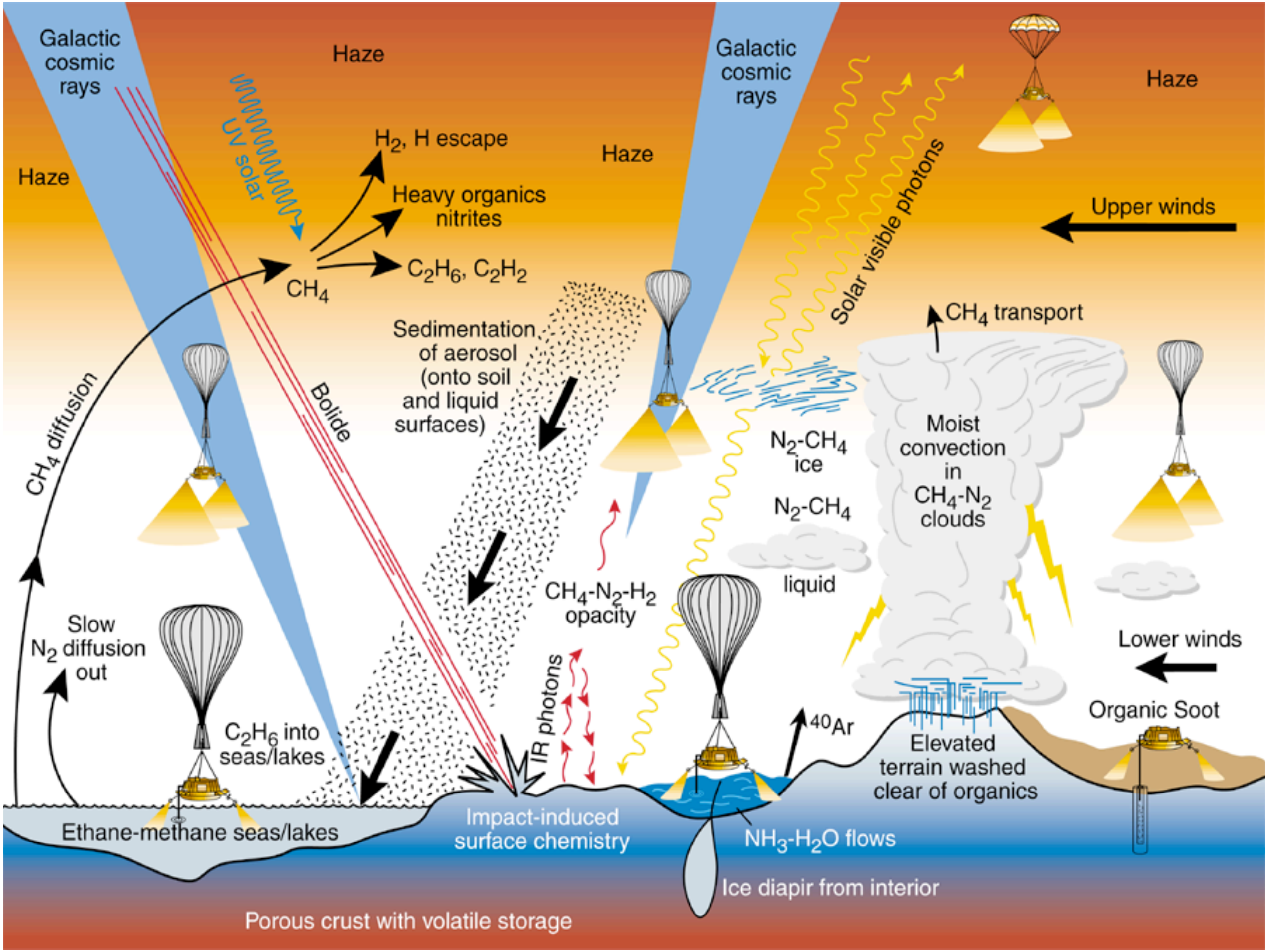
1. Define locally the atmospheric parameters and properties, such as the temperature, the density, the heat balance and the atmospheric electricity of the atmosphere from the ground up to 1600 km, during entry and descent phase with the probe and cruising phase with the Montgolfière.
2. Determine locally the thermal and chemical structure (including haze, noble gases and isotopes) of the lower atmosphere (from a certain altitude TBD in the stratosphere and to the ground) during the descent phase of the probe; the same at different longitudes and with some latitudinal coverage with the Montgolfière around 10 km in altitude.
3. Constrain the atmospheric origin and evolution, and the photochemistry. Origin of volatiles and outgassing processes.
4. Determine locally with the Montgolfière and the probe the dynamics and heat balance of the atmosphere (circulation, tides, waves, eddies, turbulence, radiation)
5. Determine the meteorology (dynamics, rain, clouds, evaporation, atmospheric electricity, etc)

    with the Montgolfière at equatorial and mid-latitudes

    locally with the lander
6. Measure climatic (seasonal and long term) variations, stability, methane and ethane in the lower atmosphere and surface (by comparing with Huygens)

Focus of TSSM in situ science objectives

7. Map the surface around equatorial and mid-latitudes as well as above the landing location in the optical, IR, stereo and radar with resolution <1 m.
8. Determine the surface material from high-resolution in situ measurements; compositional context mapping of the surface from the Motgolfière.
9. Detect recent geological history
10. Measure the subsurface profiles at very high resolution (over few hundred meters spot size and a vertical resolution < 3 m) to
    a) detect sedimentary processes and to reconstruct their history.
    b) detect structures of tectonic or cryovolcanic origin, and correlate these structures with the surface morphology for understanding the history of dunes.
    c) Detect subsurface structures of cryovolcanic origin (e.g. channels, chambers, etc.)
11. Detect and measure the depth of shallow subsurface reservoirs of liquid (hydrocarbons)
12. Surface-atmosphere interaction (volatiles, energy, momentum, PBL)
13. Gravity field



Galactic cosmic rays
Haze
UV solar
H_2, H escape
Heavy organics nitrites
C_2H_6, C_2H_2
CH_4
Haze
Galactic cosmic rays
Solar visible photons
Haze
Upper winds
Haze
CH_4 diffusion
Bolide
Sedimentation of aerosol (onto soil and liquid surfaces)
CH_4 transport
N_2-CH_4 ice
N_2-CH_4
liquid
Moist convection in CH_4-N_2 clouds
CH_4-N_2-H_2 opacity
IR photons
Slow N_2 diffusion out
C_2H_6 into seas/lakes
Lower winds
Organic Soot
^{40}Ar
Elevated terrain washed clear of organics
Ethane-methane seas/lakes
Impact-induced surface chemistry
NH_3-H_2O flows
Ice diapir from interior
Porous crust with volatile storage

Dunes

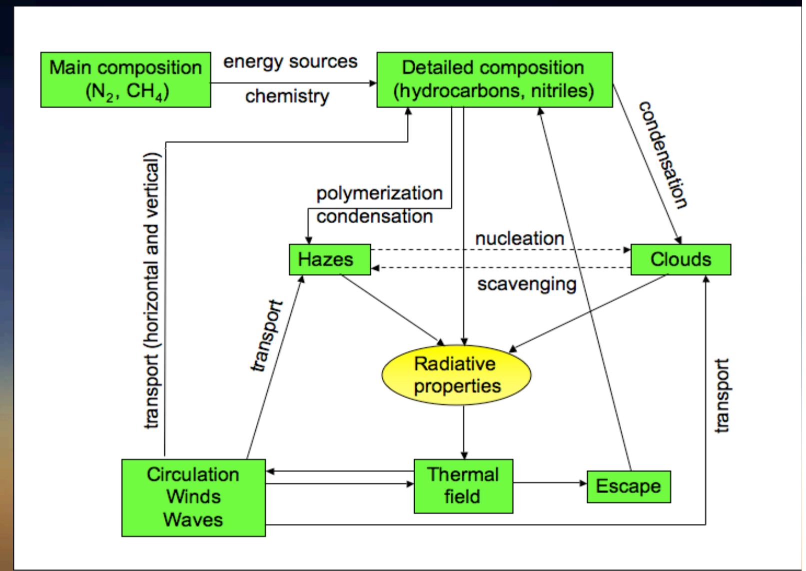
Cassini/RADAR/Titan

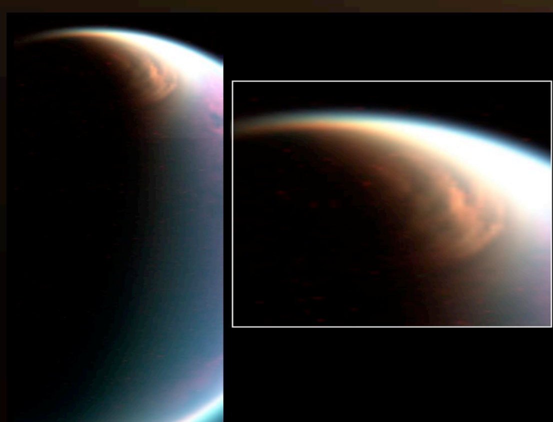
Earth

Titan‘s neutral atmosphere

Motto: Understand the workings of Titan‘s atmosphere!

- Atmospheric structure
  - –Determine the near-surface temperature and temperature profile in the polar troposphere
- Atmospheric dynamics:
  - –Search for evidence of atmospheric tides and waves
  - –Map out the meridional circulation and its change with seasons
  - –Seek evidence of orographic and convective winds and clouds
- Atmospheric composition and chemistry:
  - –Hydrocarbons, nitriles, polymerisation





- Climate and alkanological cycle:
  - –Characterise the structure and evolution of the polar vortex
  - –Map the seasonal and latitudinal variation in the tropospheric methane abundance
  - –Determine the physical and chemical properties of clouds
  - –Search for evidence of methane outgassing and evaporation from lakes
- Quantify the coupling of the surface and atmosphere in terms of mass and energy balance

Titan's surface and subsurface

.... In general

Surfaces are the boundary layer between interiors and atmospheres and record all processes passing this transition.

Surfaces and sub-surfaces are accessible for measurements and thus can constrain theoretic models

The *geological context* will provide the current state of surfaces and sub-surfaces as well as their evolution as a function of time.

Basic surface science -> characterize the boundary layer

atmosphere/surface interaction (exchange of components)

surface (geology, composition, lateral exchange of materials)

surface/sub-surface (physical properties, exchange of components)

Titan’s surface

Understand Titan’s Geological System

What are the processes of liquid cycles and recharging mechanisms and their relation to cryo-volcanism, tectonics and erosion?

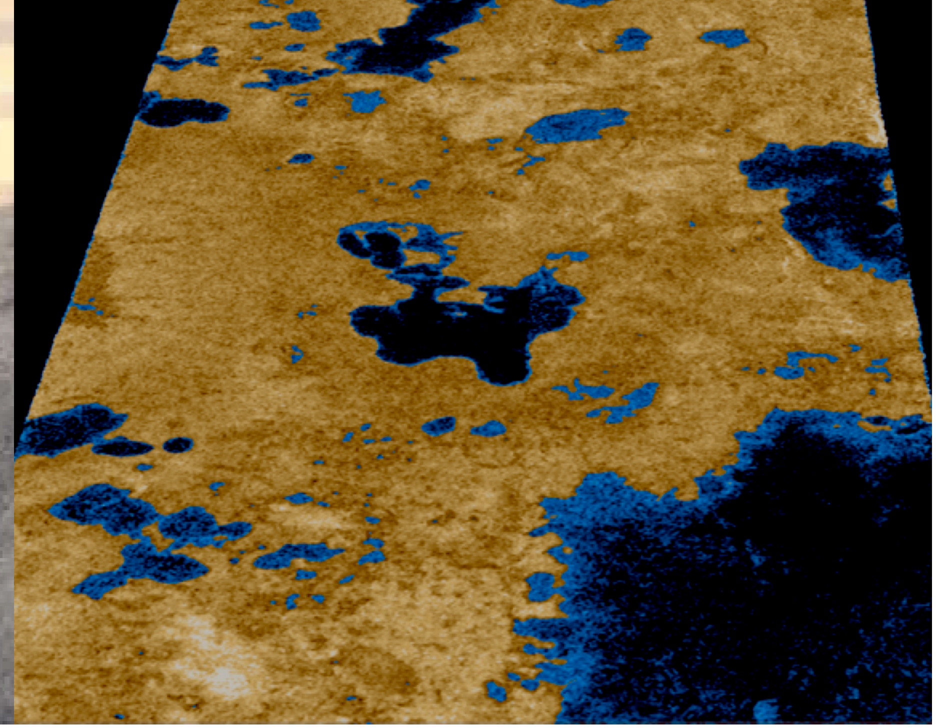
What are the depth and composition of the interior liquid layer (if any), the structure of the crust and depth of the "methanifer”, the sources of atmospheric methane.

What is the crustal history

Understand Titan’s liquids

Are the “lakes and seas” filled with methane and ethane, and do they extend to a subcrustal hydrocarbon “methanofer” system over a larger area of Titan?

Where is all the ethane? Are these processes affected by a deep-water ocean, e.g. through fissures by tidal flexing?



Titan's surface

Understand Titan's Geological System

What are the processes of liquid cycles and recharging mechanisms and their relation to cryo-volcanism, tectonics and erosion?

What are the depth and composition of the interior liquid layer (if any), the structure of the crust and depth of the "methanifer", the sources of atmospheric methane.

What is the crustal history

-> need to obtain imaging and topography with resolutions <100 m;
-> need highest-resolutions for specific sites (< 1 m);
-> need global compositional mapping with resolutions < 1 km;
-> need to determine the depth and vertical structure of surface and subsurface deposits and methanofers

Understand Titan's liquids

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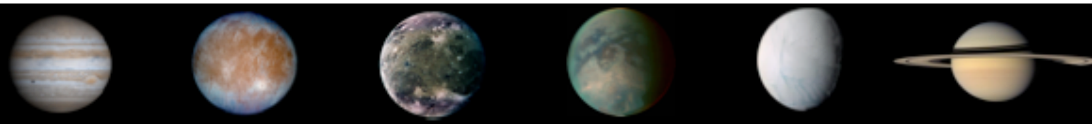
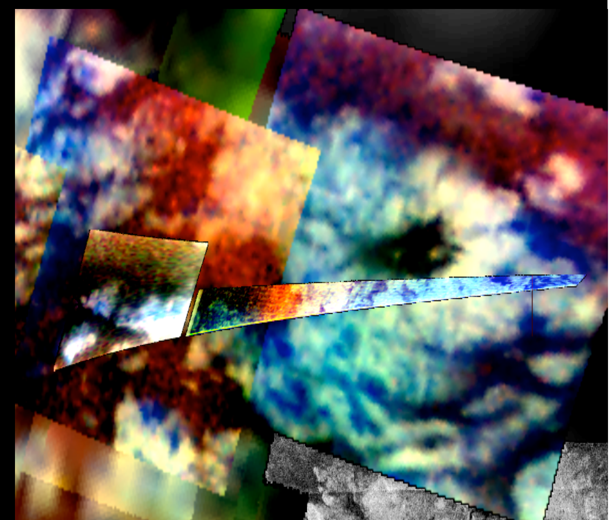
Where is all the ethane? Are these processes affected by a deep-water ocean, e.g. through fissures by tidal flexing?

-> need to obtain mapping with resolutions <100 m;
-> need highest-resolutions for specific sites (< 1 m);
-> need global compositional mapping with resolutions < 1 km;
-> need to determine the depth and vertical structure of surface and subsurface deposits and methanofers;
-> need measures of the gravity field

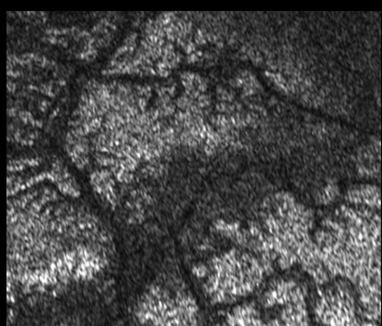


Titan’s surface

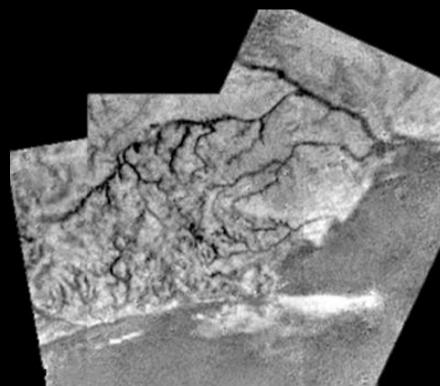


Understand Titan’s surface composition

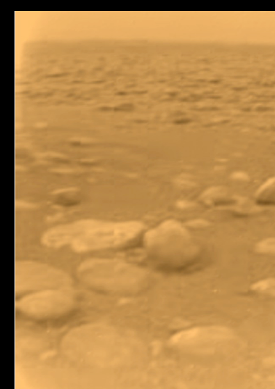
-What is the composition of surface and subsurface material?
-What are the nature of chemical alteration processes



T28 RADAR/SAR r~300m



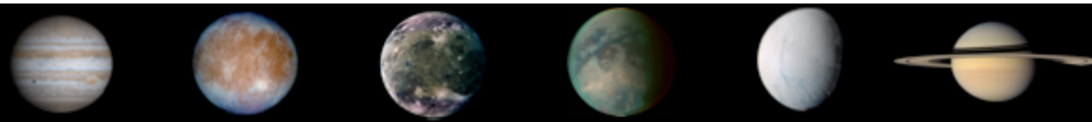
Huygens DISR r ~17 m



DISR from the ground

Understand Titan’s atmosphere/surface interaction

-What are the seasonal- and longer-scale dependencies of the distribution of materials across the surface?
-What is the long term history of dunes?

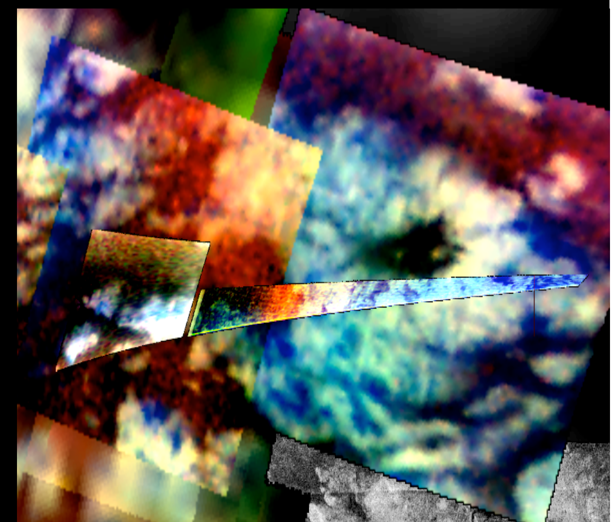


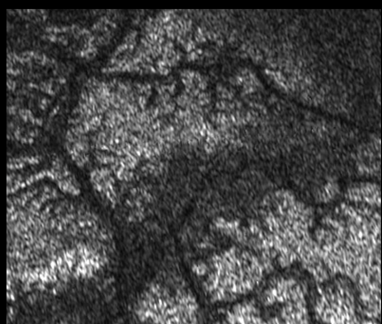
Titan's surface

Understand Titan's surface composition

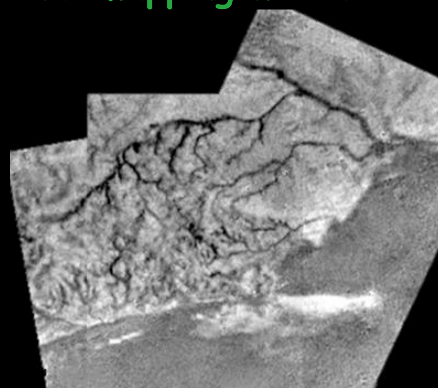
-What is the composition of surface and subsurface material?
-What are the nature of chemical alteration processes

-> need in-situ "mineralogical"/chemical analyses;
-> need compositional context and infrared imaging from a near-surface platform
-> need global compositional mapping with resolutions < 1 km;

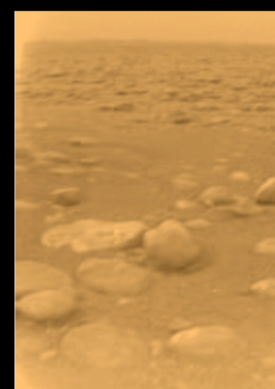




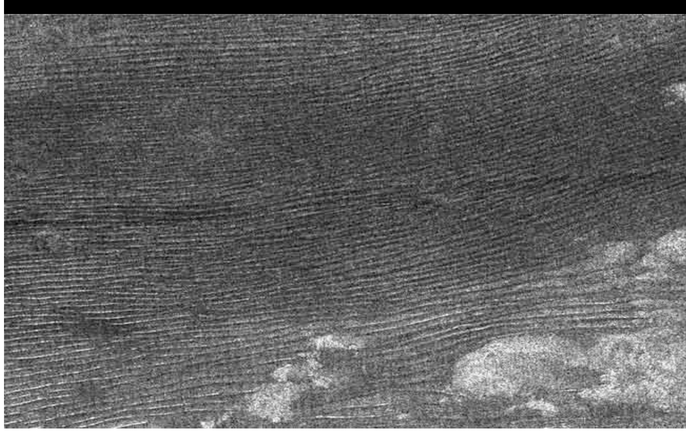
T28 RADAR/SAR r~300 m



Huygens DISR r~17m



DISR from the ground



Understand Titan's atmosphere/surface interaction

-What are the seasonal- and longer-scale dependencies of the distribution of materials across the surface?
-What is the long term history of dunes?

-> need multiple coverage of mapping instruments;

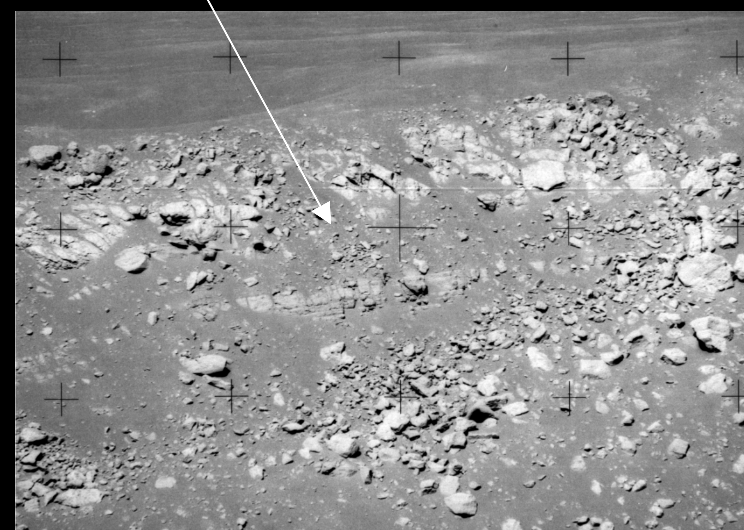
Science Objectives: Titan Surface

Science Goals	Observables	Lander/Balloon Gondola	Orbiter
Geology Characterize geologic (volcanism, tectonism, impact cratering, stratigraphy) and geomorphologic (erosion, sediment transport, aeolian, fluvial, marin) surface processes	• IR imaging (global, regional, local) • Altimetry	• IR imager (Balloon) • Radar altimeter (Balloon) • Stereo Imaging (Lander/Balloon)	• NIR/IR imager • Radar altimeter
Surface Composition Characterize composition (organics, volatiles, condensates, searching for NH_3) and physical properties of the surface à relation to geological and geomorphological surface processes	• in-situ analysis • IR spectral mapping (global, regional, local) • Radiometer	• close up imager • IR imaging spectrometer (Balloon Gondola) •In-situ Analysis (Lander)	• NIR – MIR imaging spectrometer

Resolution

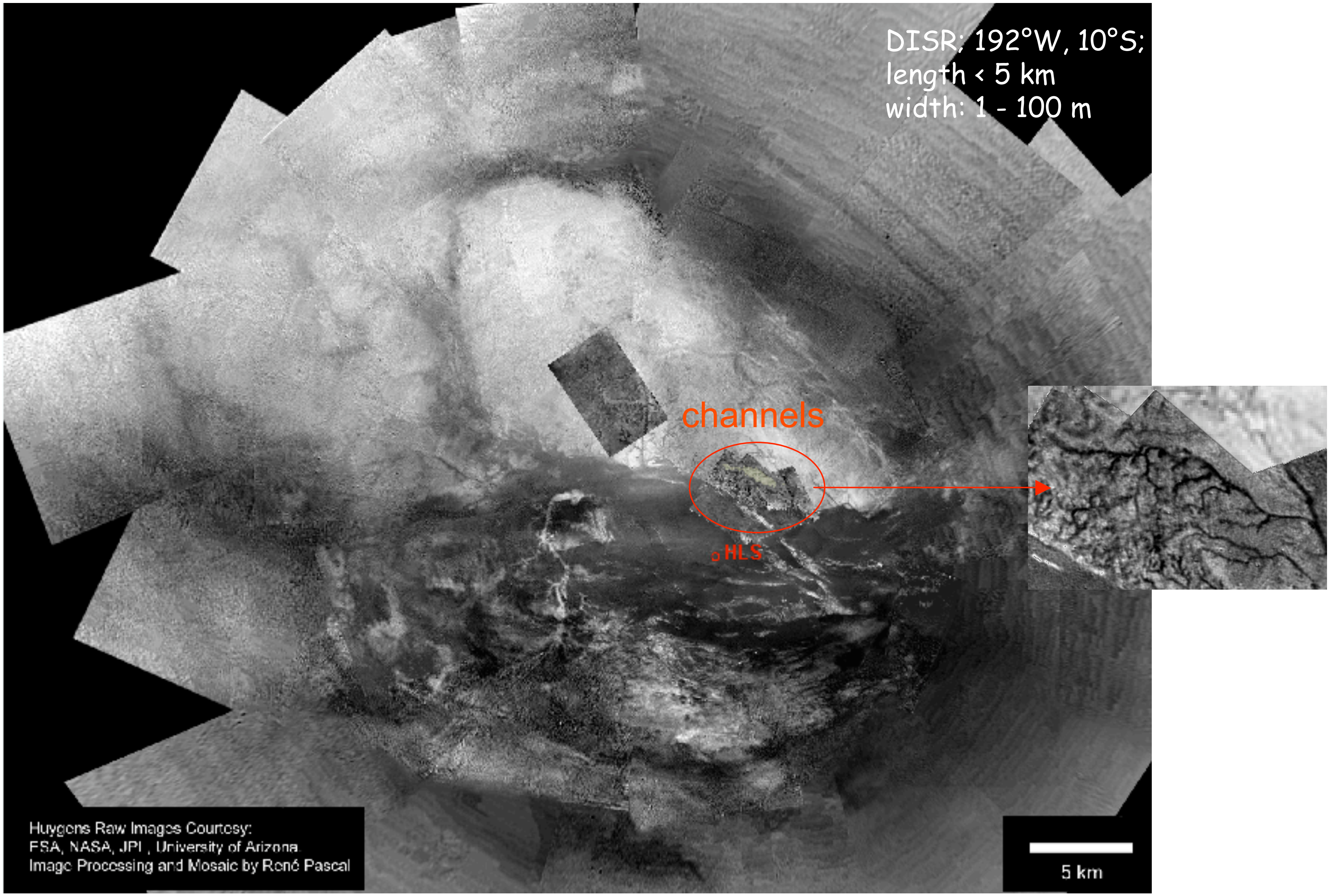
Hadley Rille, Mare Imbrium

Resolution < 1m yield the possibility to analyze bedrock

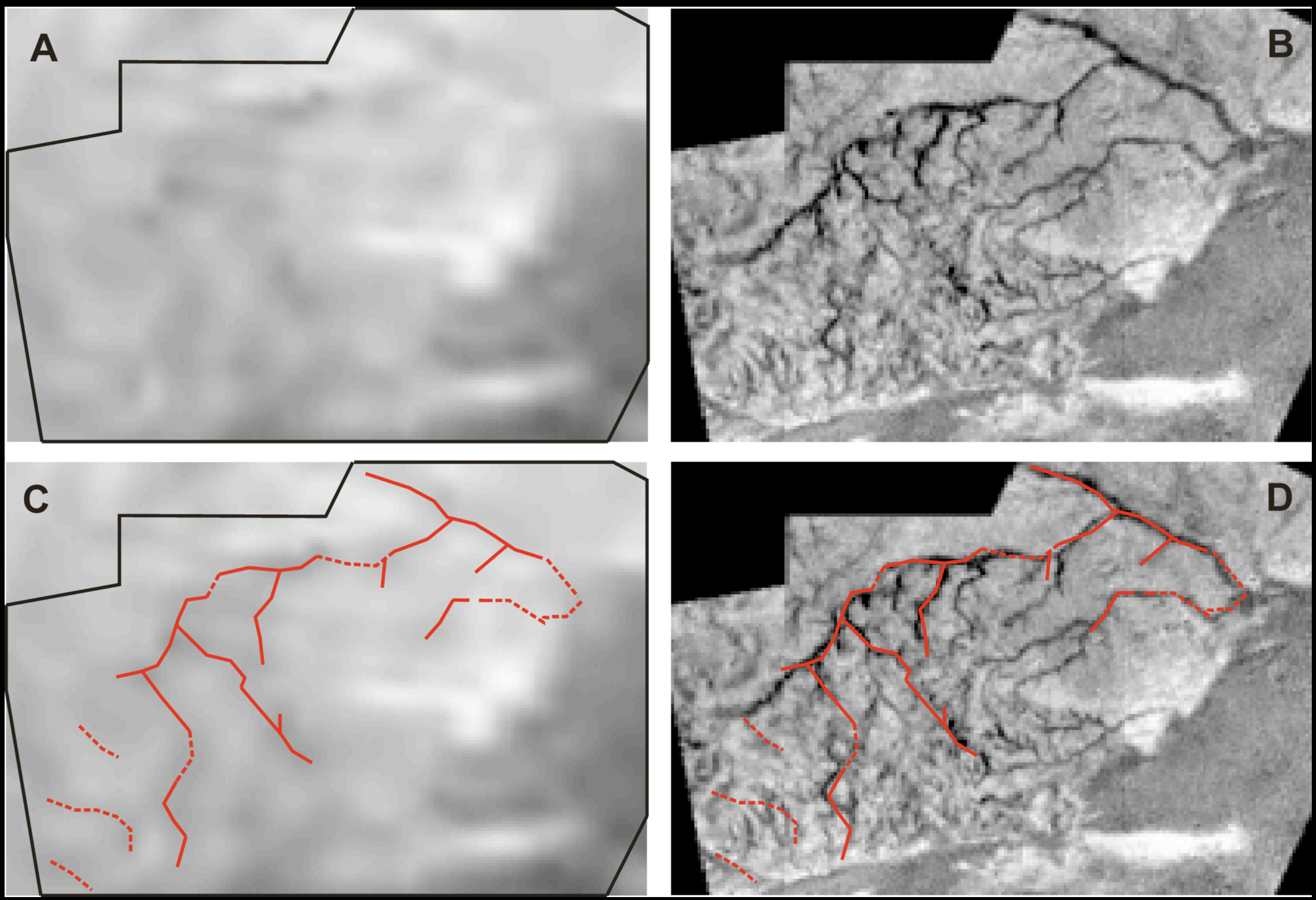


Apollo 15, Hadley Rille:
Layered basalts in the rim

Erosion on Titan

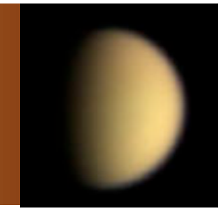


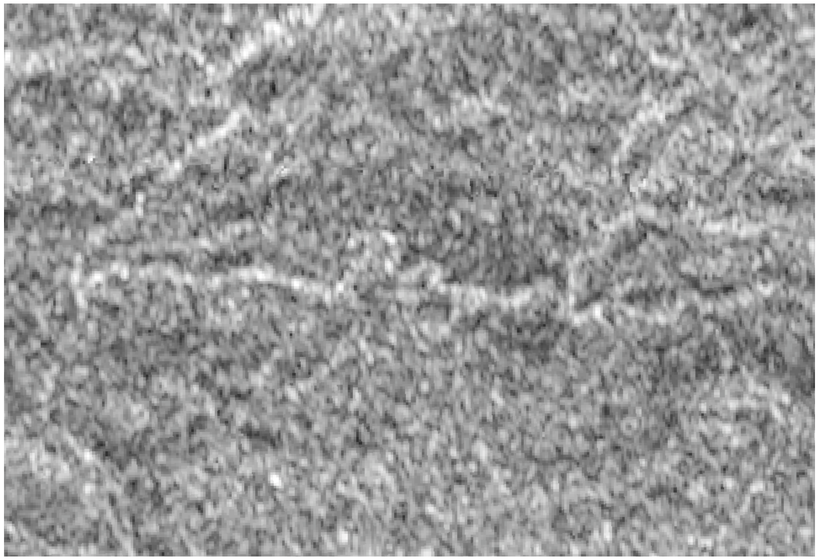
Erosion on Titan



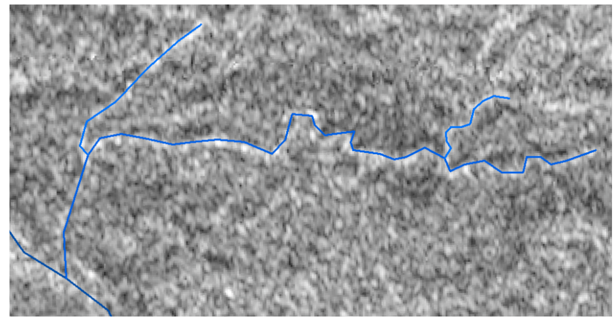
HLS DISR 01/14/2005 at VIMS Resolution

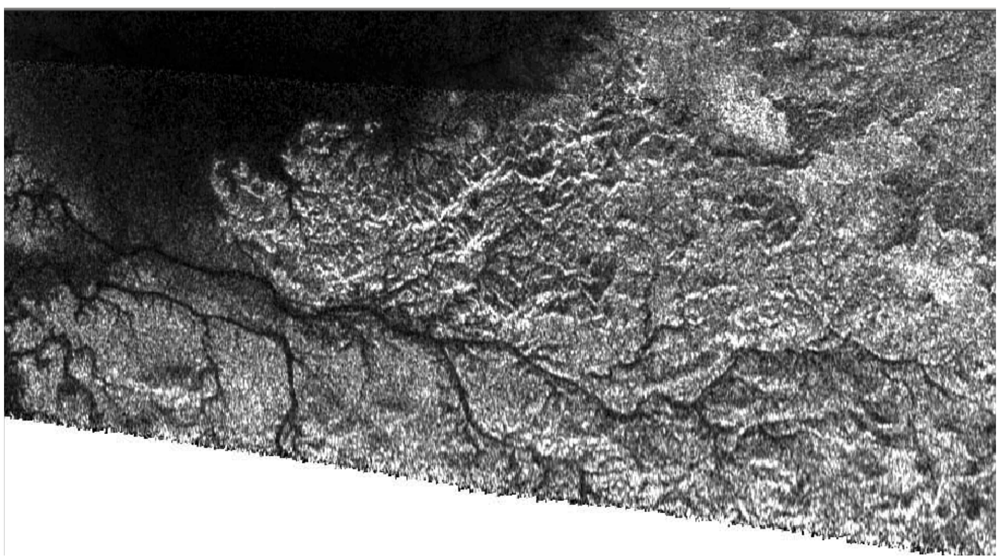
Erosion on Titan



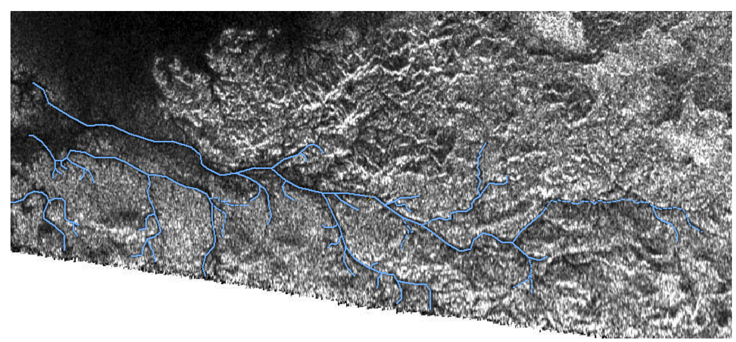


Titan, radar T13
140°W, 8°S
350m/pixel





Titan, radar T28
255°W, 75°N
1.4km/pixel



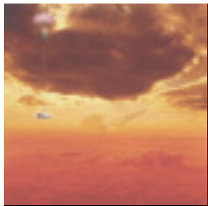
Instrument Request for GEOLOGY and GEOMORPHOLOGY

IR-imaging:

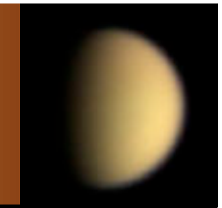
windows :	at least 2 and 5 μm
resolution:	Orbit 50 m @ 1500 km
	Balloon 5m @ 15 km
	Lander 1mm - 1m @ 1m - 1.5 km
S/N	> 100

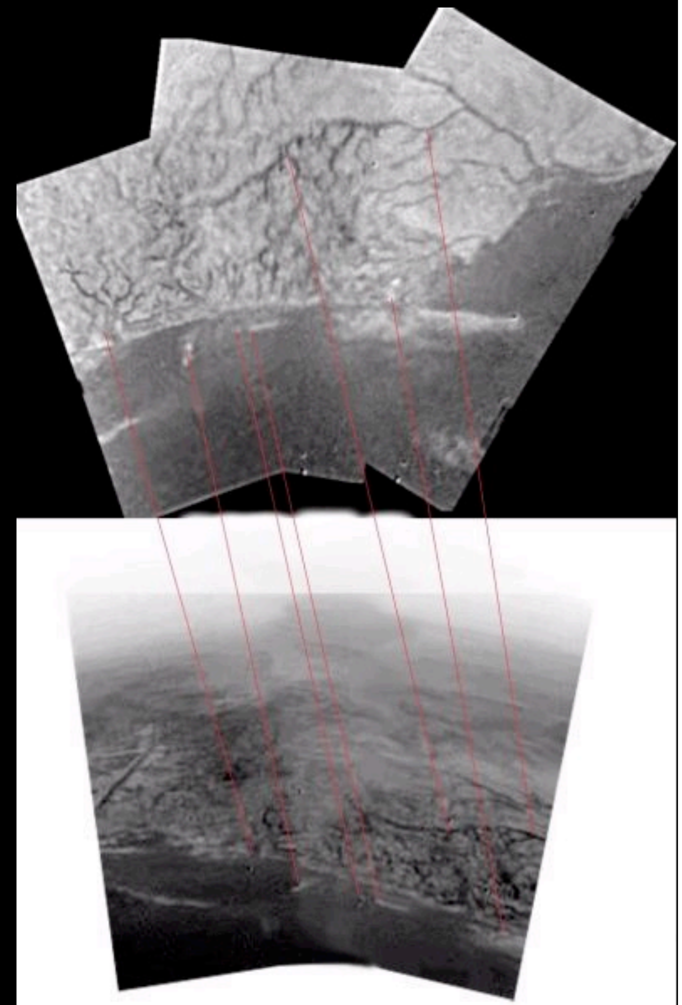
options:	stereo capabilities
	limb sounding capabilities

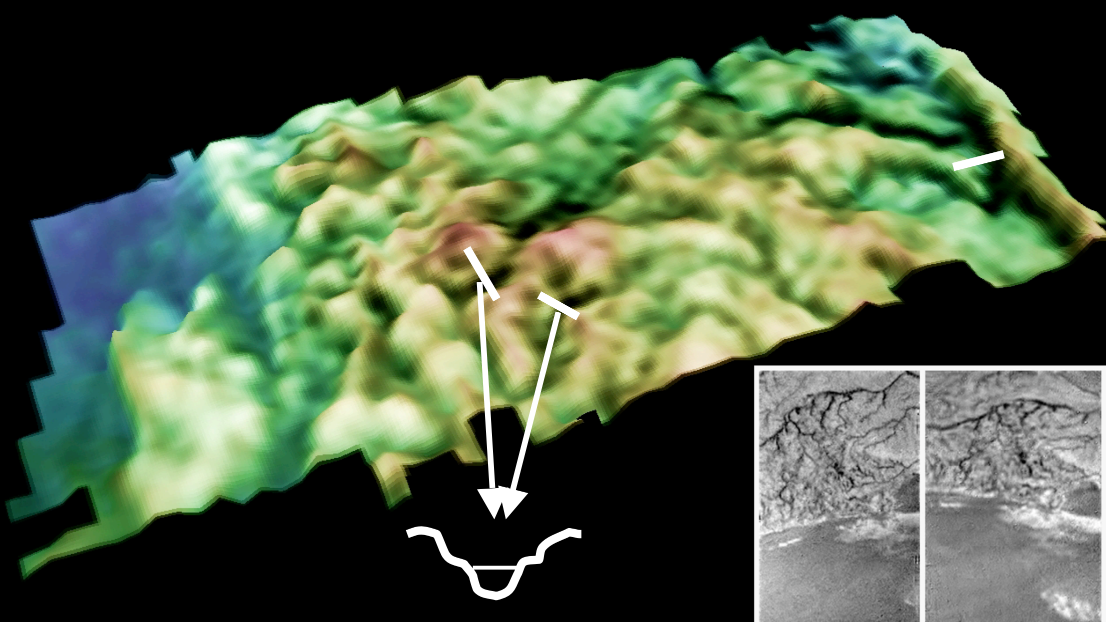
additional science capabilities:
Mapping spectral units
Estimation of cloud altitude and haze distribution
(cross calibration from orbit, balloon and ground)



Titan







Instrument Request for TOPOGRAPHY

Laser Altimeter:

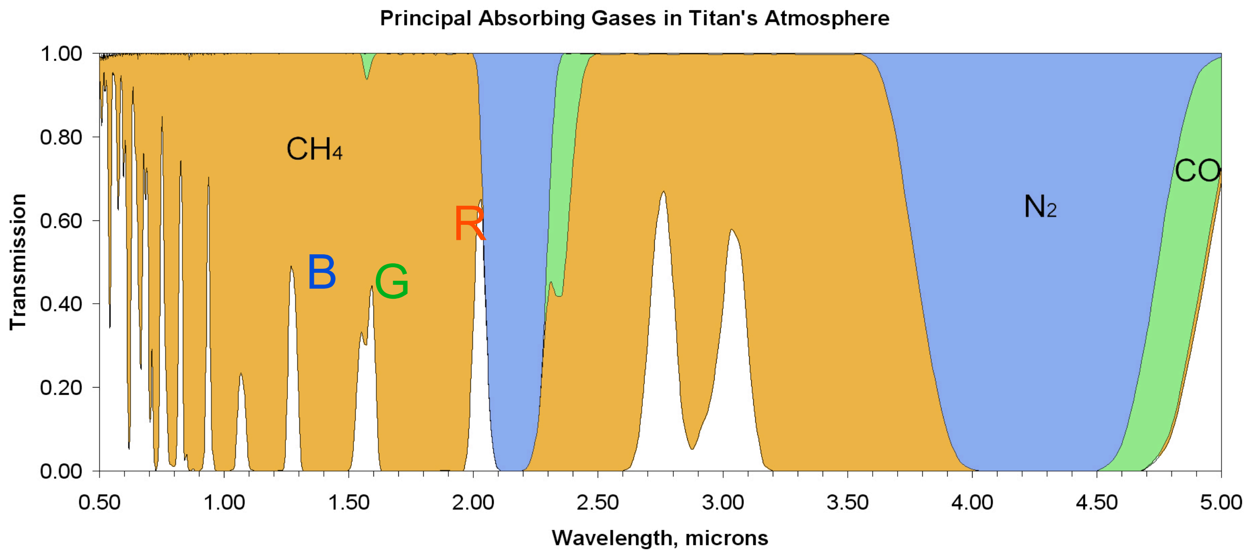
Orbiter tbd -> Radar

Balloon

	LA@Tandem	MicroLaser Option
Laser	10 mJ	0.1 mJ
Laser Wavelength	1064 nm	1064 nm
Laser Shot Length	8-10 ns	8-10 ns
Shot Rate	100 Hz	10 kHz
Data Rate	8000 bit/s	tbd.
Laser Beam Divergence	0.1 mrad (tbc.)	0.1 mrad
Laser Spot on Surface (@10 km)	1 m	1 m
Operation Power	10 W	5 W
Receiver Optics Diameter	4 cm	2 cm
Dimensions	23 x 16 x 14 cm	tbd.
Nominal Lifetime	1 year or 30 Mio shots	1 year
Total Mass	5 kg	5 kg

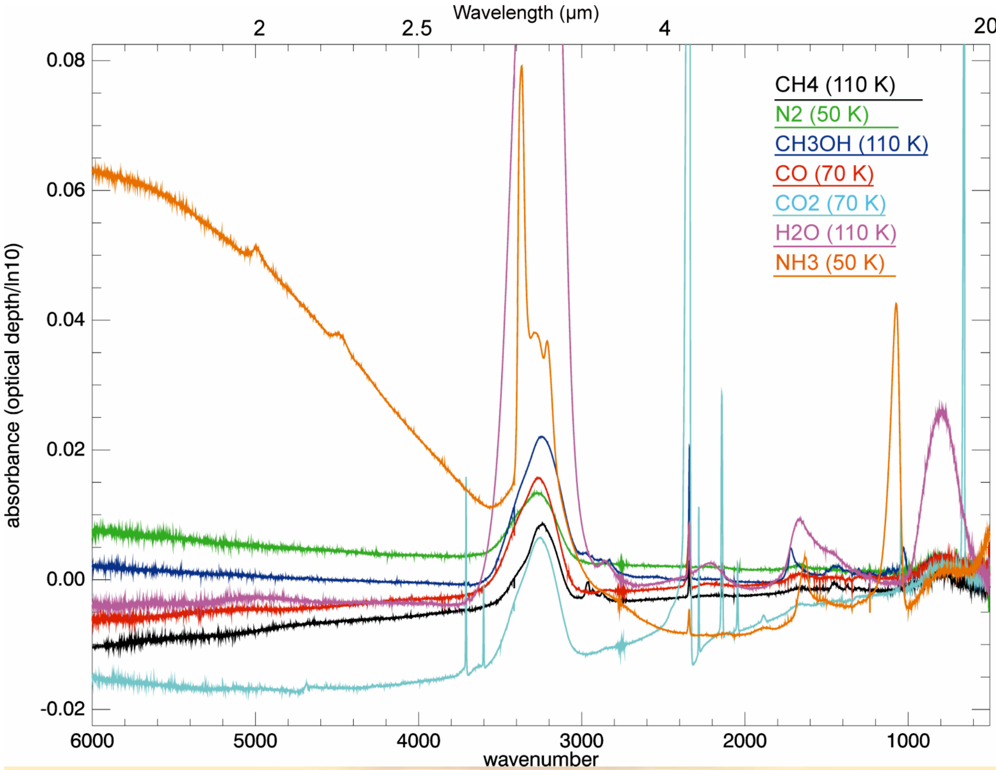
Instrument Request for COMPOSITION

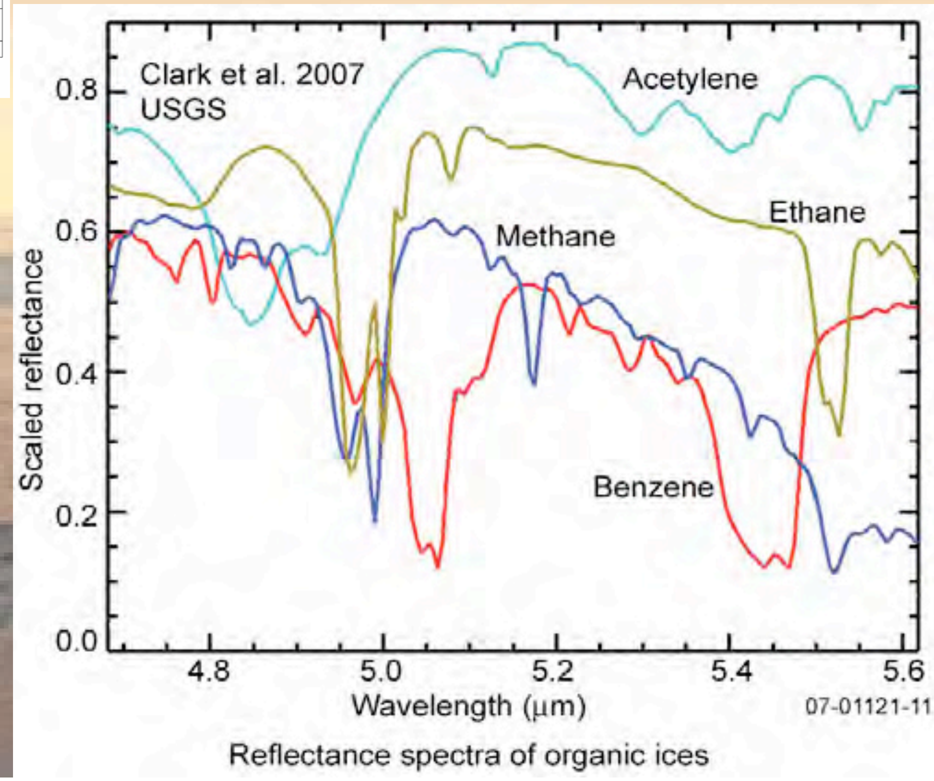
IR-spectrometer:
Wavelength range : near-IR (0.9-6 μ)

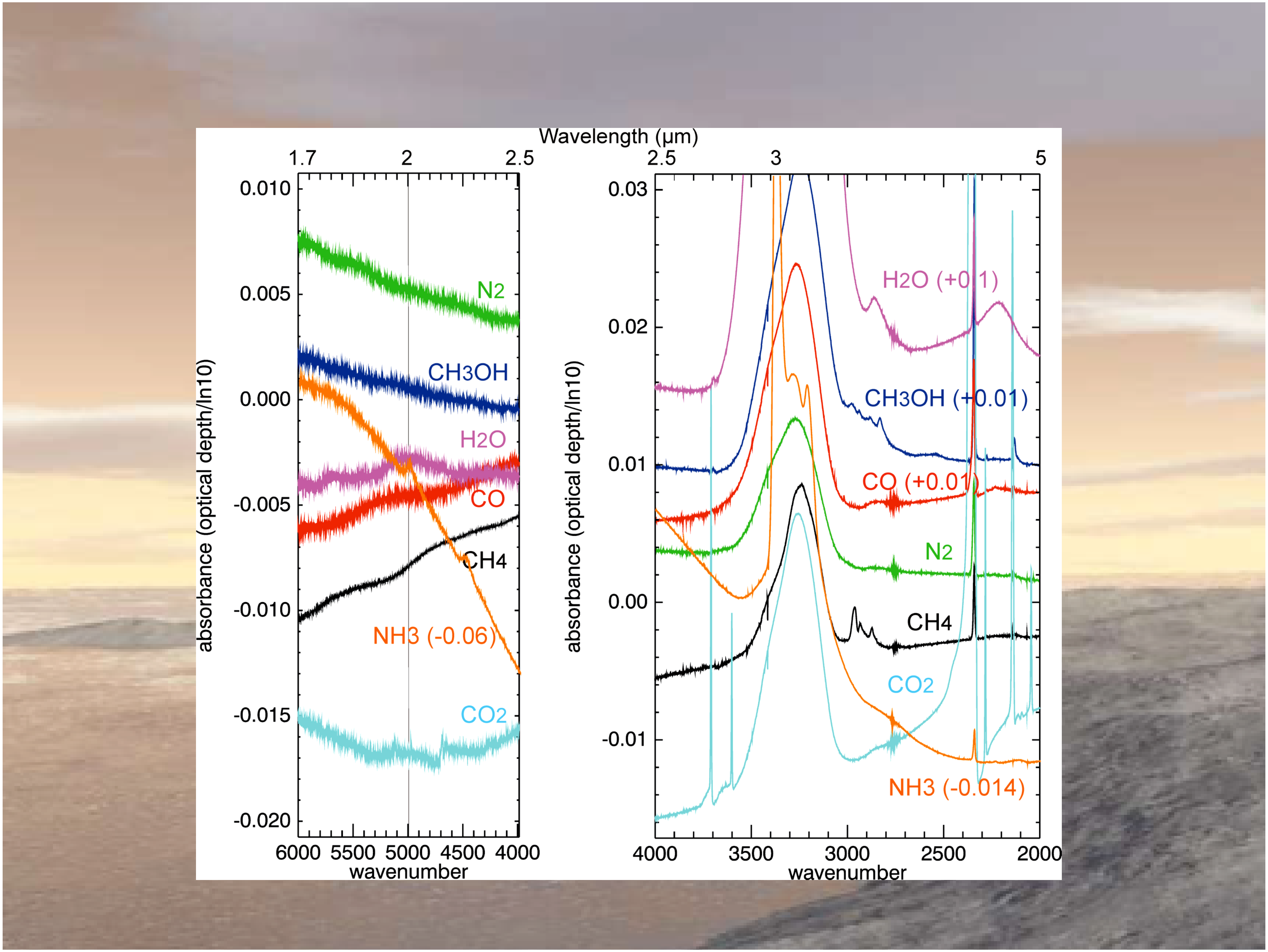


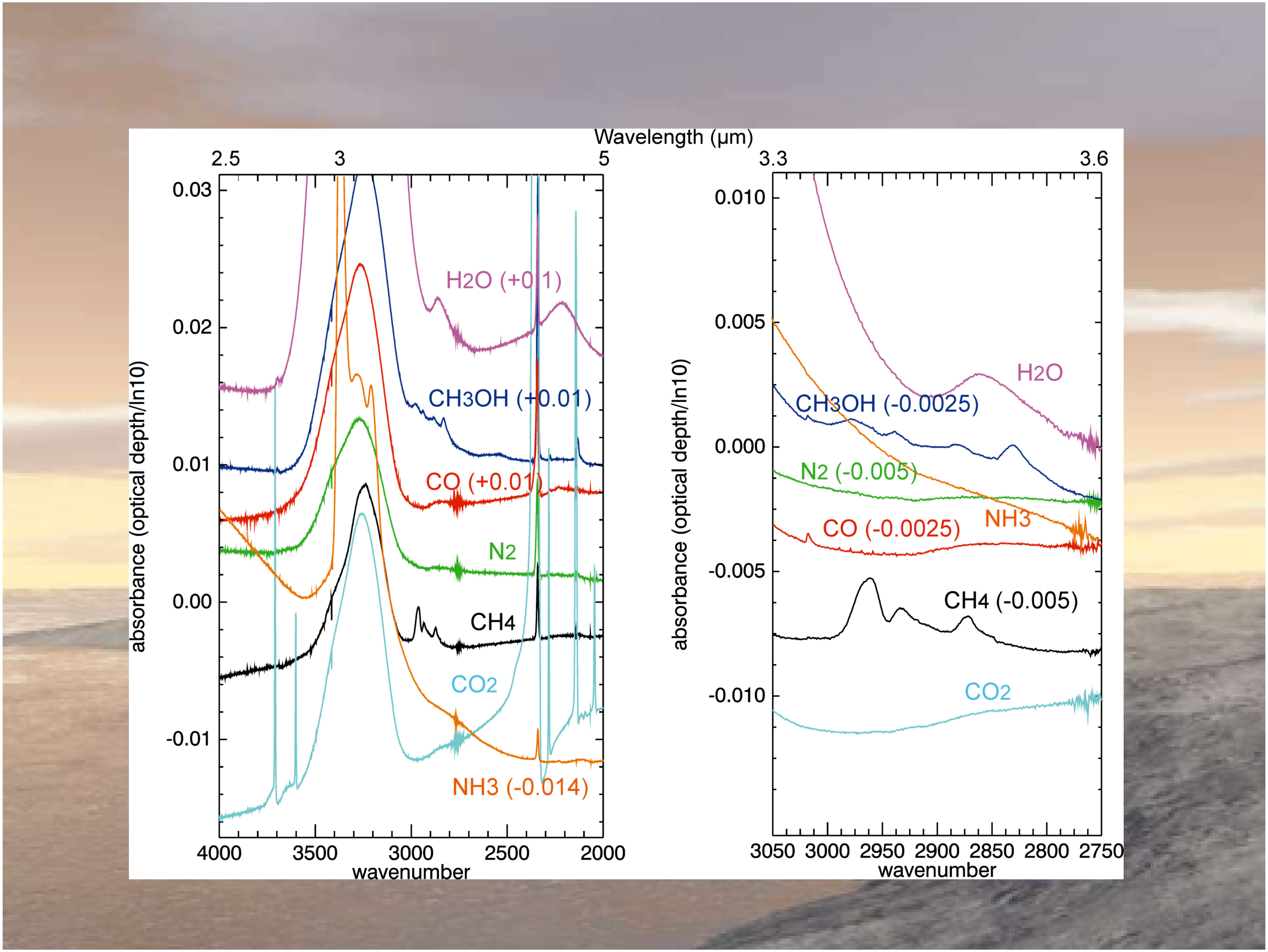
Species	IUPAC name	Common name	Molar mass ($g\ mol^{-1}$)[b]
C_2H_4	ethene	ethylene	28.0532
C_2H_2	ethyne	acetylene	26.0373
CH_3C_2H	propyne	methyl-acetylene	40.0639
C_4H_2	1,3-butadiyne	diacetylene	50.0587
C_6H_6	cyclohexatriene	benzene	78.1118
HCN	formonitrile	cyanide	27.0254
CH_2NH	methyleneimine	-	29.0413
CH_3CN	ethanenitrile	acetonitrile	41.0520
C_2H_3CN	2-propenenitrile	acrylonitrile	53.0627
HC_3N	2-propynenitrile	cyanoacetylene	51.0468
C_2N_2	ethanedinitrile	cyanogen	52.0349
C_4N_2	2-butynedinitrile	dicyanoacetylene	76.0563

Spectra of organics

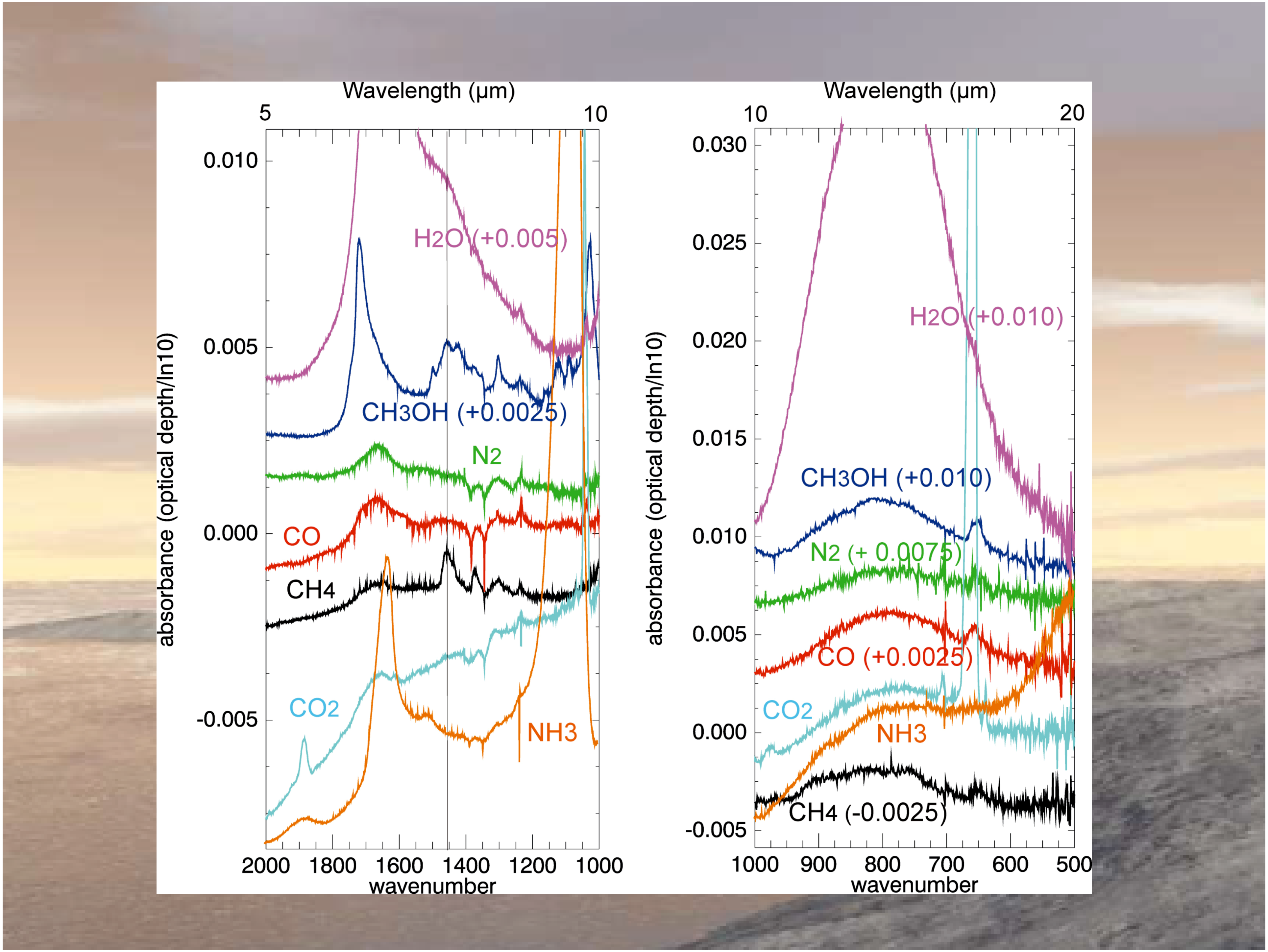





Wavelength (μm)
1.7
2
2.5
2.5
3
5
0.010
0.005
0.000
-0.005
-0.010
-0.015
-0.020
absorbance (optical depth/ln10)
N2
CH3OH
H2O
CO
CH4
NH3 (-0.06)
CO2
6000
5500
5000
4500
4000
wavenumber
0.03
0.02
0.01
0.00
-0.01
H2O (+0.1)
CH3OH (+0.01)
CO (+0.01)
N2
CH4
CO2
NH3 (-0.014)
4000
3500
3000
2500
2000
wavenumber



Wavelength (μm)
2.5
3
5
3.3
3.6
0.03
0.02
0.01
0.00
-0.01
H2O (+0.1)
CH3OH (+0.01)
CO (+0.01)
N2
CH4
CO2
NH3 (-0.014)
4000
3500
3000
2500
2000
wavenumber
absorbance (optical depth/ln10)
0.010
0.005
0.000
-0.005
-0.010
H2O
CH3OH (-0.0025)
N2 (-0.005)
NH3
CO (-0.0025)
CH4 (-0.005)
CO2
3050
3000
2950
2900
2850
2800
2750
wavenumber
absorbance (optical depth/ln10)



Wavelength (μm)
5
10
0.010
0.005
0.000
-0.005
absorbance (optical depth/ln10)
H2O (+0.005)
CH3OH (+0.0025)
N2
CO
CH4
CO2
NH3
2000
1800
1600
1400
1200
1000
wavenumber
Wavelength (μm)
10
20
0.030
0.025
0.020
0.015
0.010
0.005
0.000
-0.005
absorbance (optical depth/ln10)
H2O (+0.010)
CH3OH (+0.010)
N2 (+ 0.0075)
CO (+0.0025)
CO2
NH3
CH4 (-0.0025)
1000
900
800
700
600
500
wavenumber

Instrument Request for
COMPOSITION

IR-spectrometer:

wavelength range :	5 - 8 μm
R:	1000
resolution:	Orbit 1km @ 1500 km
	Balloon 100m @ 15 km
	Lander RAMAN/Libs

options: cross calibration from orbit, balloon and ground

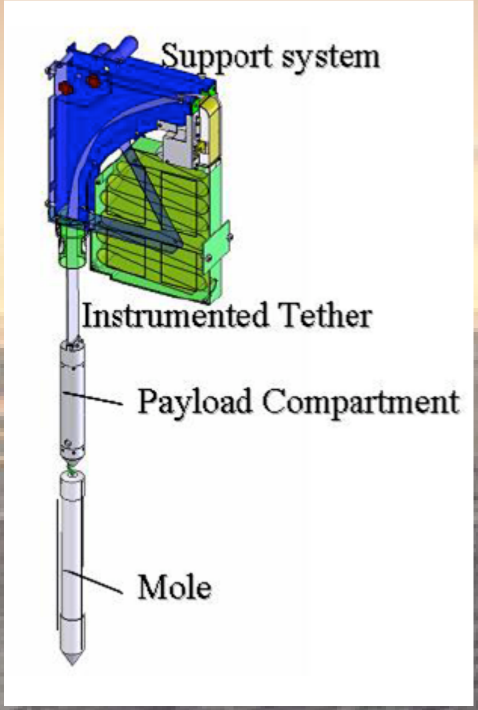
X-ray diffractometer (XRD) +
X-ray fluorescence spectrometer (XRF) on lander
for element abundances

Basic science -> characterize the boundary layer

surface/sub-surface (physical properties, exchange of components)

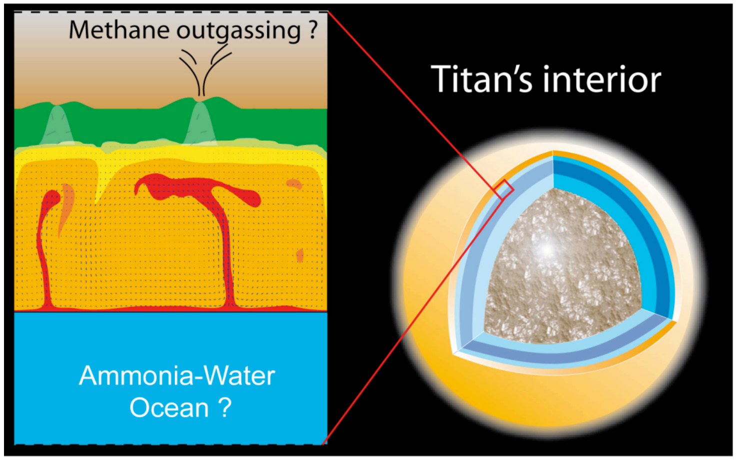
To understand surface/subsurface interactions we need a capability to drill

- Heaters and Temperature Sensors (Heat Flow, thermal conductivity and diffusivity)
- Permittivity Probe (electrical conductivity and relative permittivity, Porosity, Layering)
- Densitometer (Density)



Interior & early evolution Science Goals

- Present interior structure
  - Structure, heterogeneities in radial mass distribution.
  - Tidal Heating.
  - Geochemical constraints on bulk composition and internal differentiation.
  - Presence and extent of liquid water.
- Tidally induced deformation, magnetic field and seismicity
  - Depth to liquid water reservoirs, radial extent and electrical conductivity.
  - Lateral variations in thickness and rigidity of the overlying icy crust.
- Heat sources, cryovolcanism and eruptive processes
  - Intrinsic heatflow, near-surface thermal gradient.
  - Delivery of nitrogen and methane to the surface.
  - Geochemical and geophysical constraints on bulk composition and internal differentiation
- Interior-surface interactions
  - Size and state of the rocky core, structure of the crust and depth of the "methanifer",
  - sources of atmospheric methane
  - What is the crustal history?
- Early Evolution
  - Noble gas isotopic ratios (Ar, Kr, Xe, Ne) of surface materials and aerosol depositions, $^{14}N/^{15}N$ isotopic ratios, presence of H_2, N_2 or CO at mass 28, presence of NH_3, gas/dust ratio of plumes.



Titan's internal structure

We need

to determine topography, gravity and magnetosphere

to have in situ seismic and isotopic measurements

Science Objectives: Titan Interior I

Science Goals	Observables	Lander/Balloon Gondola	Orbiter
Structure, Mass Distribution Characterize deep interior heterogeneity; assess compensation state of topography, e.g. Xanadu; decipher crustal structure (e.g., « methanifer » depth?).	• Location and extent of gravity anomalies • Static gravity field observations • Rotational state	• Long-period accelerometer / gravimeter • Surface magnetometer (?) • GPR radar • Gondola with long-lived surface probe capability • Radio science	• Radar altimeter • GPR radar mode (?) • Radio Science • Micro-Gradiometer (?)
Low to mid-order gravity field observations Determine global hydrostatic state and deduce moment-of-inertia factor.	• Independent measurements of $J_2 = -C_{20}$ from polar orbits and C_{22} from equatorial orbits • Static gravity field observations	• Long-period accelerometer / gravimeter	• Radio Science • Micro-Gradiometer (?)

Science Objectives: Titan Interior II

Science Goals	Observables	Lander/Balloon Gondola	Orbiter
Ocean, Tides, and Implications for Orbital History Prove/disprove existence and extent of internal liquid layer; determine thickness of outer chlathrate-ice shell; deduce intrinsic heatflow to estimate how much orbital energy is dissipated.	• Tidally-induced surface deformation and gravity changes • Amplitude and phase of second-degree tidal Love numbers h_2 and k_2 • Time-variable gravity field observations • Plasma-induced magnetic field fluctuations • Time-variable magnetic field observations • Thermal gradient • Surface temperature	• Long-period accelerometer / gravimeter • Tiltmeter • Surface magnetometer (?) • GEP (short-period seismometer, thermal probe, permittivity probe, temperature sensors) • GPR radar	•Radar altimeter • GPR radar mode (?) • Radio Science, e.g., LoS-Doppler and/or Differential Sat-Sat-Tracking • Micro-Gradiometer (?) • Magnetometer • Radiometer

Science Objectives: Titan Interior III

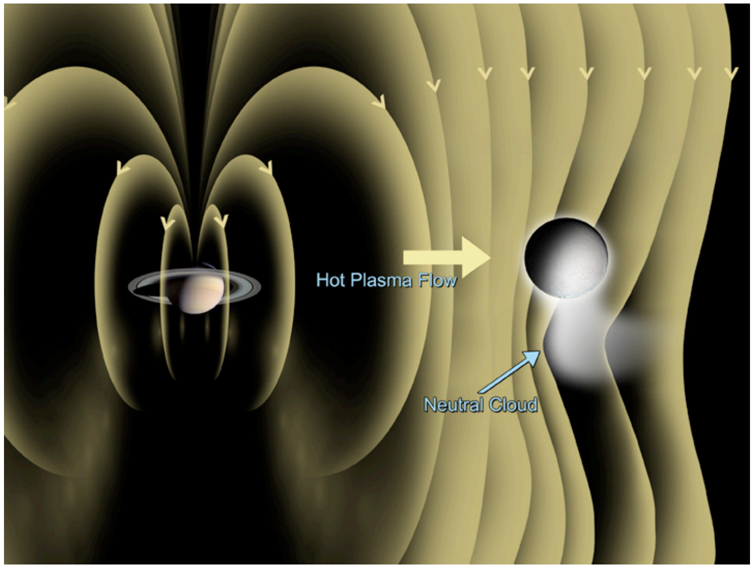
Science Goals	Observables	Lander/Balloon Gondola	Orbiter
Global topography Determine morphology and location of topographic features, tectonic structure, viscous crater relaxation state.	• Ranging • Stereo Imaging	• Altimeter • Imager	• Radar altimeter • Stereo Imaging Science
Endogenic Dynamics Determine morphology and location of tectonic features; correlate tectonic features with cryovolcanic activities; estimate surface ages; deduce intrinsic heatflow.	• Ranging • Stereo Imaging • Thermal gradient • Surface temperature	• GEP (short-period seismometer, thermal probe, permittivity probe, temperature sensors)	• Radar altimeter • Stereo Imaging Science • Radiometer

Science Objectives: Titan Interior IV

Science Goals	Observables	Lander/Balloon Gondola	Orbiter
Volatile inventory Origin of volatiles / Silicate volcanism [?] / Hydrothermalism Characterize composition and thermal state of near-surface layer; deduce intrinsic heatflow.	• Mechanical, thermal, and dielectric properties of the subsurface • Thermal gradient • Surface temperature	• GEP (short-period seismometer, thermal probe, permittivity probe, temperature sensors) • GCMS • H_2O & CH_4 humidity	• Thermal IR spectrometer • Microwave Sounder • Radiometer
Composition Sample and analyze gases, solids, and liquids; estimate surface composition and physical properties of organic veneer layer; correlate surface properties with cryovolcanic and tectonic evolution.	• In-situ observations of cryovolcanic source regions and liquid surface reservoirs (lakes) • ^{14}C-dating	• GEP (short-period seismometer, thermal probe, permittivity probe, subsurface sampling, temperature sensors) • GCMS • Balloon with sample retrieval capability • ^{14}C-chrono-stratigraphy suite	• Near-mid-IR mapping spectrometer • Dust detector • UV spectrometer

Enceladus as a system

If we had penetrators…

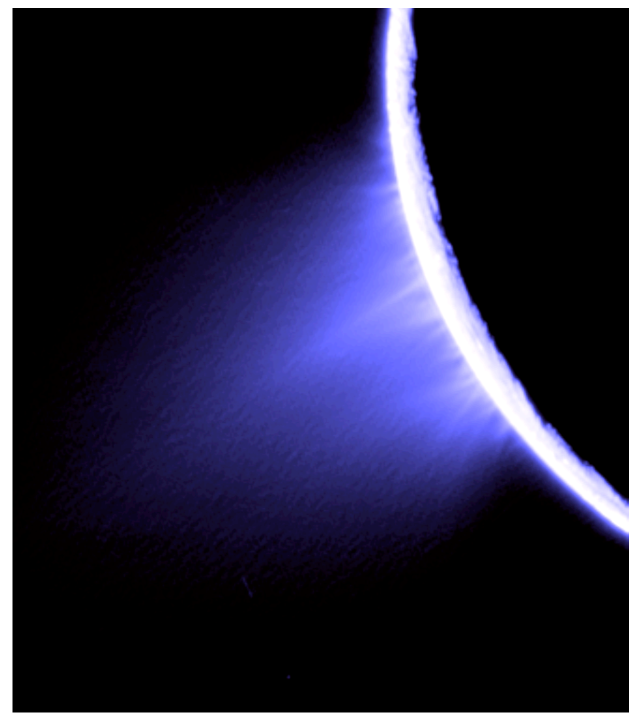


•**Origin, nature and properties of the jets and plume**

(including dynamic properties, temporal variability, spatial distribution of gas/dust)

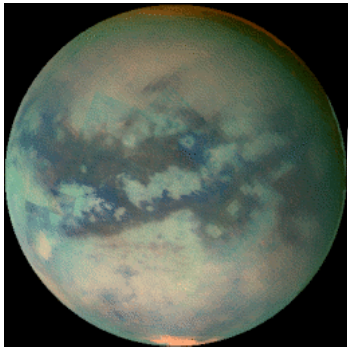
•**Existence, depth and extent of sub-surface liquid water** (implications for heat sources, e.g. tidal heating, and composition, including possibly clathrates)

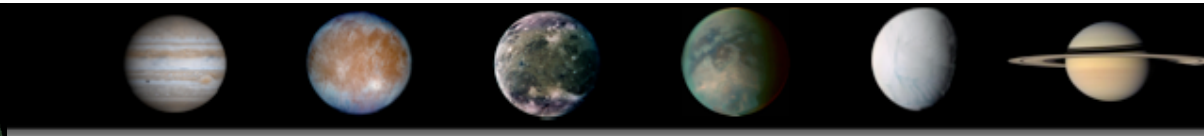
•**Signs of past/present life** (including organic inventory)



•**Other Objectives include:**

- •**Characterize the surface and its heterogeneity** (including resurfacing and tectonic processes, vent structure, impact craters)
- •**Characterize the interior** (including structure and mass distribution, gravity field, global topography, endogenic and exogenic dynamics)
- •**The impact of Enceladus on the magnetosphere** (including magnetospheric processes, plasma loading effects)
- •**Influence of Enceladus on other satellites** (including surface contamination)
- •**Influence of Enceladus on ring structure**
- •**Determination of dust flux into system**





Astrobiology : Titan

Similarities of Titan with the Earth

- Atmosphere, structure, composition, greenhouse properties, climate similarities (haze ↔ ozone)

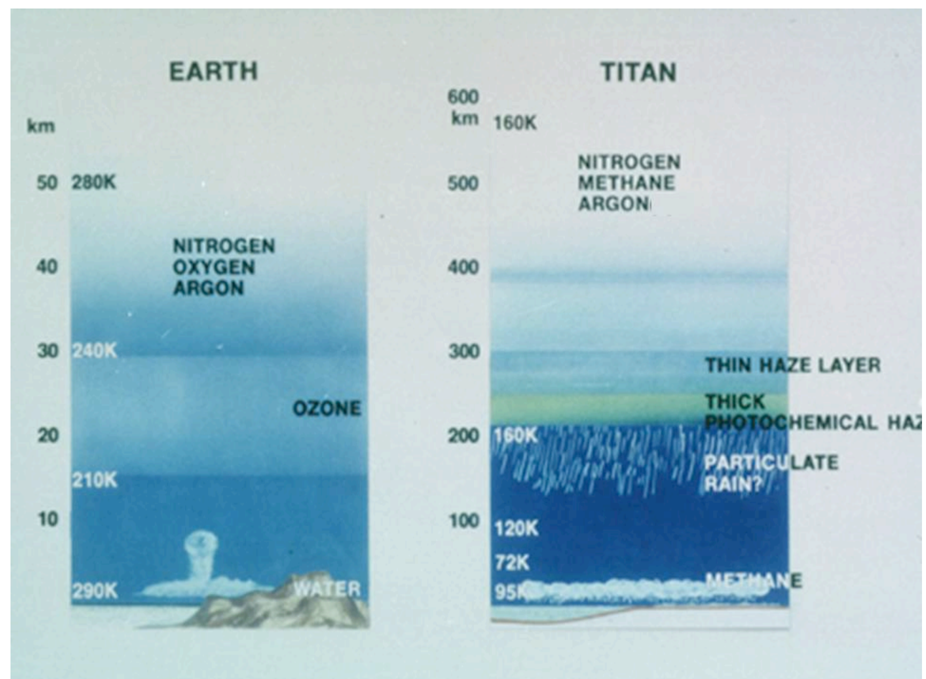
- Many geological similarities (liquid bodies, fluvial networks, dunes, (cryo)-volcanism, mountains, tectonics, erosion, impact craters …)

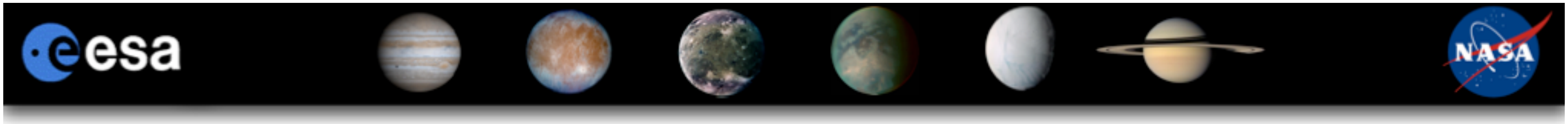
- Ice on Titan ↔ rock on Earth

- Methane cycle ↔ water cycle

BUT : Still to be fully understood!!

In addition: an organic chemistry with many similarities with the early Earth's prebiotic chemistry





Astrobiology objectives

Prebiotic organic chemistry issues

On Titan

- In the atmosphere (gas and aerosols) from the ionosphere to the troposphere
- On the surface and in the subsurface

But the molecular composition, potential chirality & degree of chemical complexity of organics in aerosols and on the surface are still to be determined

In Enceladus

- Organic chemistry in the internal structure. To be studied!!

Habitability and Life

Emergence & development of Life requires liquid water – carbon compounds - energy => all probably present in Titan & Enceladus!

Astrobiological exploration of Titan

*explore Titan as a SYSTEM, i.e coupled interior, surface, atmosphere-ionosphere-beyond system

*determine D/H in water, Xe, Kr, Ar to 10^{-11} mole fraction

*determine $^{36/38}Ar$, isotopes of other noble gases (??)

*characterize chemical composition of surface material

- Key to Titan's mystery is in its surface!
- Future missions should focus on
  - nature of surface-subsurface material
  - pre-biotic complex organic molecules (~1000 Da)
  - D/H in H_2O-ice?
  - cryovolcanism: where is the smoking gun?
  - H_2 outgassing: current serpentinization, or surface dissociation of organic material
  - $^{12}C/^{13}C$ in surface organics?

Example of science vs payload for Ionosphere/magnetosphere

Objectives	Measurements	Instruments
P0 : Agnostosphere	• Densities of aerosols, positive ions, negative ions (10-10000 amu), stable and reactive H, C, N containing neutral species with resolution of 0.01 amu. • Direct measurements of neutral winds and ion velocities above 800 km. • Vertical profiles of electron and ion temperatures (above 700 km) • Vertical profiles of neutral temperature (above 400 km) • Measurements must cover the globe and differing solar illumination	*Orbiter:* • Advanced Ion & Neutral Mass Spectrometer [INMS] • Advanced Aerosol Analyser [AA] • PLASMA PACKAGE – See note below • UV Spectrometer [UVS] • Energetic Neutral Atom Imager & Composition Analyser [ENA] • Accelerometer [ACC] • Radio Science [RSE] • Millimetre & Sub-mm Spectrometer [MSS] • Auroral & Airglow Photometer [AAP] *Entry Probe:* • Advanced Ion & Neutral Mass Spectrometer [INMS] • Advanced Aerosol Analyser [AA] • Dual Langmuir Probe [DLP] • Dual Magnetometer [DM] • Radio Science [RSE] • Accelerometer [ACC] • Plasma Analyser [PA] *Balloon:* • Advanced Ion & Neutral Mass Spectrometer [INMS] • Advanced Aerosol Analyser [AA] • Auroral & Airglow Photometer [AAP] *Lander:* • Dual Magnetometer [DM]
P0 : Upper Atmosphere Chemistry	• Densities of aerosols, positive ions, negative ions (10-10000 amu), stable and reactive neutral H, C, N, containing species with resolution of 0.01 amu. • Direct measurements of neutral winds and ion velocities above 800 km. • Vertical profiles of electron and ion temperatures (above 700 km) • Vertical profiles of neutral temperature (above 400 km) • Atmosphere measurements must cover the globe and differing solar illumination • Measurements of global plasma and magnetic field structure of induced magnetosphere for different conditions of Saturn Local Time and magnetospheric dynamics • Measurements in Saturn's equinox period (2023-2025) with solar eclipses of Titan by Saturn providing a unique opportunity to study the photochemistry of Titan's atmosphere.	
P0 : Magnetotail / Wake studies	• Measurements of global plasma and magnetic field structure of induced magnetosphere for different conditions of Saturn Local Time and magnetospheric dynamics out to ~ 10 R_T with emphasis on the unexplored magnetotail-wake region • Measurements concerning ion loss rates for different chemical species through the tail/wake region under varying magnetospheric conditions • Densities of positive ions, negative ions (10-10000 amu), stable and reactive neutral species with resolution of 0.01 amu. • Vertical profiles of electron and ion temperatures • Observe exospheric structure including transition region, corona, spatial and temporal variability, escape kinetics and rates of important atmospheric species • Observe ENA/LENA formation	
P0 : Internal Magnetic field	• Observe the unexplored low altitude structure of the magnetic ionopause and below • Study particle populations near magnetic ionopause	
P0 : Upper Atmosphere Dynamics	• Direct measurements of neutral winds and ion velocities above 800 km • Densities of major neutral species (N_2, CH_4) • Vertical profiles of neutral temperature (above 400 km) • Measurements must cover the globe and differing solar illumination	
P1 : Magnetic and Plasma environment	• Observe exospheric structure including transition region, corona, spatial and temporal variability, escape kinetics and rates of important atmospheric species • Observe ENA/LENA formation • Measurements of global plasma and magnetic field structure of induced magnetosphere for different conditions of Saturn Local Time and magnetospheric dynamics out to ~ 10 R_T • Measurements concerning ion loss rates for different chemical species through the tail/wake region under varying magnetospheric conditions	

Example of science vs payload for Atmosphere

Priority	Scientific objectives	Measurements	Instruments
P0	Dynamics and heat balance	*(circulation, tides, waves, eddies, turbulence, T, p, radiation)*	(sub)millimetre sounder (O) FIR/MIR spectrometer (O) ASI-ACC (O, B, L) ASI/MET (B, L)
P0	Meteorology	*(local dynamics, rain, cloud, evaporation, atmospheric electricity etc.)*	NIR mapping spectrometer (O) NIR spectrometer (B) Nephelometer (B) E field sensor (B) ASI/MET including ACC(B, L) GCMS (B) Optical rain gauge (L) Sonic anemometer (L)
P0	Climate	*(seasonal and long-term variation, climate stability, CH_4 and C_2H_6 in the atmosphere and surface)*	FIR/MIR spectrometer (O) GCMS (B) NIR mapping spectrometer (O) NIR spectrometer (B) Active laser-induced fluorescence spectrometer (B)
P1	Surface-atmosphere interaction	*(volatiles, energy, momentum, PBL)*	ASI/MET (L) Optical rain gauge (L) NIR spectrometer (B) Radar/laser/lidar (B) GCMS (B) Surface thermal property sensor (L) Active laser-induced fluorescence spectrometer (B)
P1	Chemistry and evolution	*(composition, haze formation, atmospheric origin, photochemistry, isotopes)*	FIR/MIR spectrometer (O) (sub)millimetre sounder (O) GCMS (B) Nephelometer (B) E field sensor (B) Active laser-induced fluorescence spectrometer (B)
P2	Physics of molecules	*(CH_4 absorption coeff., physical chemistry etc.)*	

Example of science vs payload for Surface

<table>
<tr><th>Objectives</th><th>Measurements</th><th>Instruments</th></tr>
<tr><td>Titan as a geological system</td><td>• High resolution global optical IR stereo mapping and radar surface detection with resolutions < 100 m
• Higher-resolution (<1 m) IR imaging from a near-surface platform</td><td rowspan="5">Orbiter :
IR stereo camera/ spectrometer
Radar/altimeter SAR
Subsurface sounder

Balloon :
IR Stereo Camera/Spectrometer
Radar/Altimeter SAR
Laser Altimeter
Subsurface Sounder
Stable Isotope Mass Spectrometer
Gas Chromatograph Mass Spectrometer

Landers:
IR Stereo Camera/Spectrometer for Context
Stable Isotop Mass Spectrometer
Gas Chromatograph Mass Spectrometer
Raman/LIBS Spectrometer
Fourier Interferometer (for atmosphere, why surface ???)
Heat Flow and Physical Properties Probe HP3
Seismometer
Meteorological Package</td></tr>
<tr><td></td><td></td></tr>
<tr><td>What is the composition, distribution and physical state of materials on and beneath Titan's surface and how is it related to geology?</td><td>•High-mass resolution in situ measurements of surface material
•Compositional context mapping from a nea-surface platoform
•Global compositional mapping with resolution < 1 km from the obiter
•Sounding radar to determine depth of surface deposits from the aerial platform</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Interaction of the surface with the interior and atmosphere</td><td>Determine methanological cycle
Interior structure</td></tr>
</table>

Example of science vs payload for Interiors

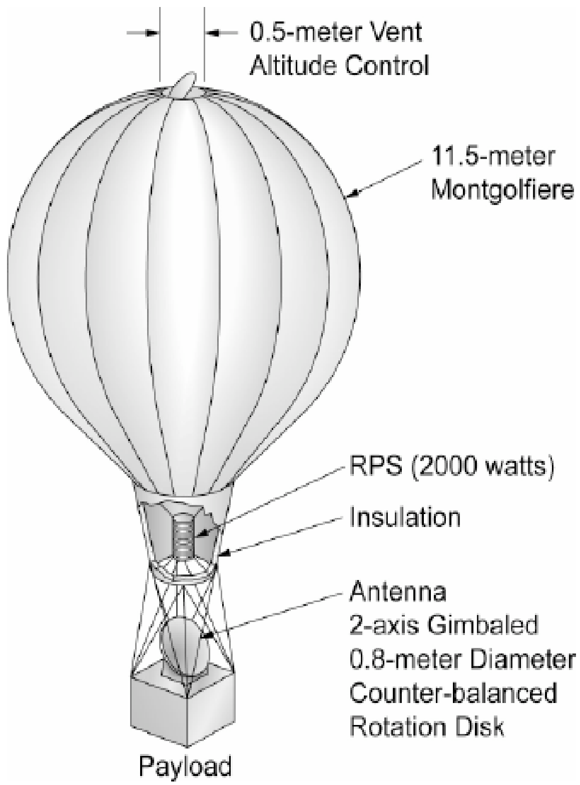
Scientific objectives	**Measurements**	**Instruments**
1) Present-day interior structure: rocky core and liquid water/ice shells 2) Tidally-induced deformation, magnetic field and seismicity 3) Heat sources, cryovolcanism and eruptive processes. 4) Early Titan: internal evolution, crust and atmosphere formation	Spatial and temporal variations of topography, gravity field and magnetic field on global and local scales. Seismic survey Subsurface sounding Near-surface thermal gradient and thermophysical properties Composition of surface materials, and of cryovolcanic magma and gases Noble gases abundances and isotopic ratios in major species.	**On a polar orbiter:** Radio science experiment, Radar or Laser altimeter, Magnetometer, HR Near-Mid-IR Multispectral + Radar Imaging **On an aerial platform:** Radar altimeter, Magnetometer, Ground Penetrating Radar, GCMS, HR Spectroscopy. **On a lander(s)**: Geophysical surface package (including seismometer & magnetometer), Surface sampling analysis package, GCMS

Example of science vs payload for Astrobiology

Objectives	Measurements	Instruments
P0 : What degree of complexity is reached by Titan's organic chemistry in the different parts of the geological system ?	• Ionosphere: ion and neutral composition within a high mass range (several 1000 Daltons) • Stratosphere-troposphere: high sensitivity (sub-ppb level) molecular and isotopic analysis of the gas phase. Chemical composition of the aerosols: Organic & inorganic analysis, elemental, molecular and isotopic analysis of the aerosols – vertical and latitudinal variations • Surface: organic & inorganic analysis-elemental, molecular, isotopic and chiral analysis of the surface materials • Subsurface : from penetrators and/or by analyzing surface materials ejected from subsurface • hydrocarbon related mineralogy for surface & subsurface • Need to analyze different areas: bright and dark regions, lake/ damp playa/ shoreline/ dune field.	*Orbiter :* * 1-2000 Daltons High resolution MS (TOF) * particles collector and analyser ? *Balloon :* * Altimeter * Stable Isotope Mass Spectrometer * Gas Chromatograph – high resolution Mass Spectrometer with capabilities for analyzing refractory materials (Laser desorption, chemical derivatization, Differential thermal analyser-pyrolyser, chemolysis) * Subcritical Water extractor – miucrocapillary Electrophoresis system *Landers:* * IR Stereo Camera/Spectrometer for Context * X-ray Fluorescence spectrometer * Stable Isotope Mass Spectrometer * Gas Chromatograph Mass Spectrometer with capabilities for analysing refractory material , and chiral GC columns * Subcritical Water extractor – microcapillary Electrophoresis system * Raman/LIBS Spectrometer * Drilling capability to analyse the subsurface and/or melting system
P0 : What degree of complexity is reached by Enceladus's organic chemistry?	• Molecular analysis of the plumes • And • Search for a subsurface ocean	*Orbiter :* * 1-2000 Daltons High resolution MS (TOF) * particles collector and analyser ? * see C2
P0 : Titan's habitability ?	• Search for evidences of internal water ocean and information on its properties • Search for episodical liquid water bodies on the surface	See C3 and C4
P1 : Life on Titan? Search for present/past biological activity	• Search for molecular, isotopic (C,S & O) and chiral biosignatures	*Landers:* * Stable Isotope Mass Spectrometer * GC-MS with chiral columns
P2 : Life on Enceladus? Search for biosignatures	• Search for molecular, isotopic and chiral (?) biosignatures	*Orbiter :* * 1-2000 Daltons High resolution MS (TOF) * particles collector and analyser ?

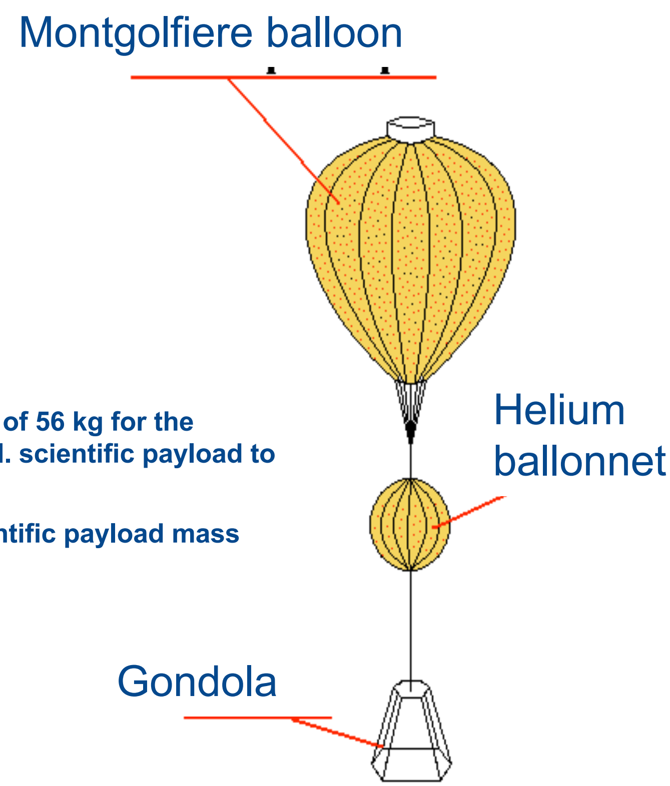
Alternative Montgolfiere balloon design for Titan

CNES – JPL Working Group on Montgolfiere Balloon design



Double wall montgolfiere design by JPL

[Ref. 1]: Jack A. Jones, James A. Cutts, Jeffery L. Hall, Jiunn-Jenq Wu, Debora Ann Fairbrother, and Tim Lachenmeier, "Montgolfiere Balloon Missions for Mars and Titan," IPPW, Athens, Greece, June 2005.

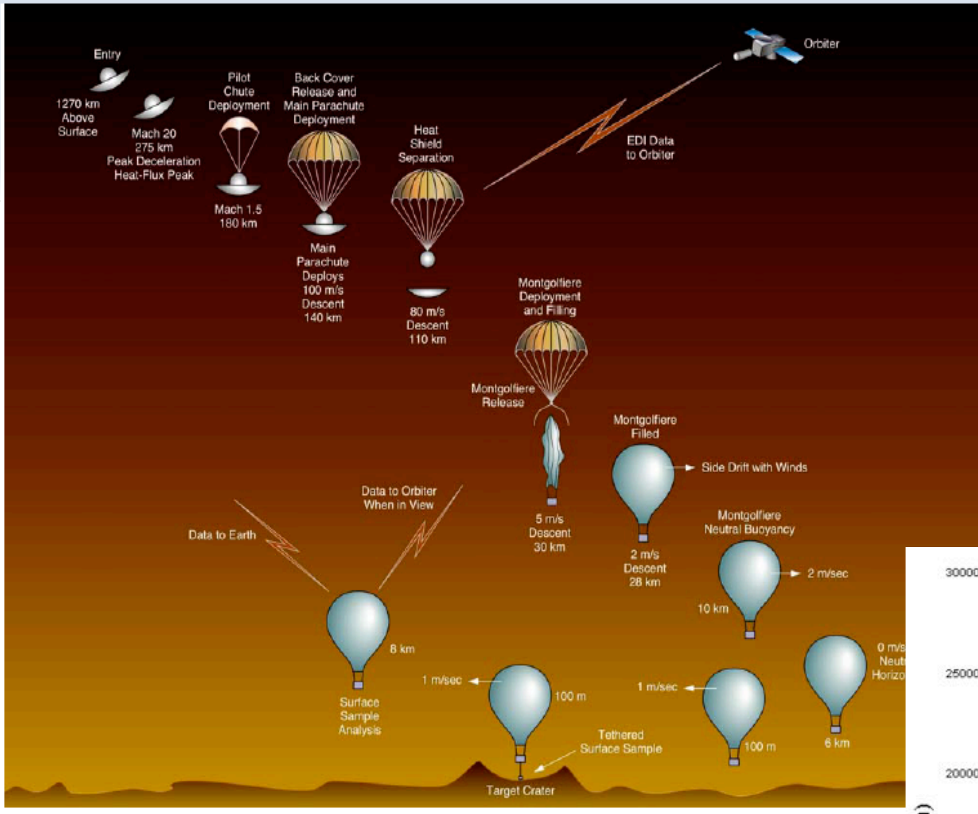


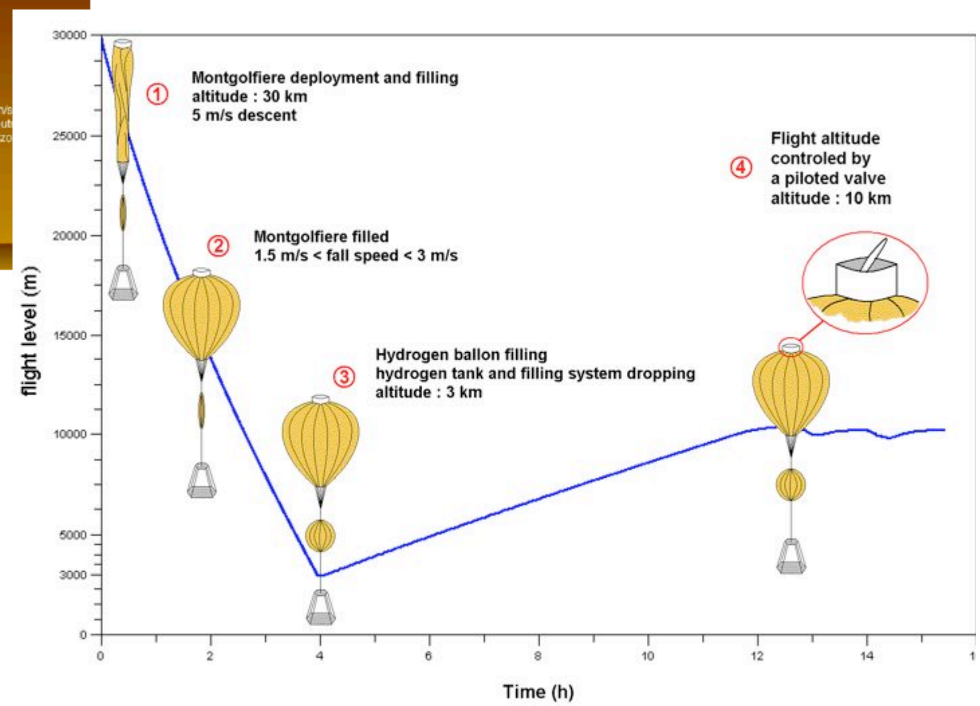
Initial guess of 56 kg for the gondola excl. scientific payload to be assessed

Typical scientific payload mass target: 30 kg

Single wall montgolfiere with additional He ballonnet to secure the descent by Cnes

Titan Montgolfier balloon mission scenario



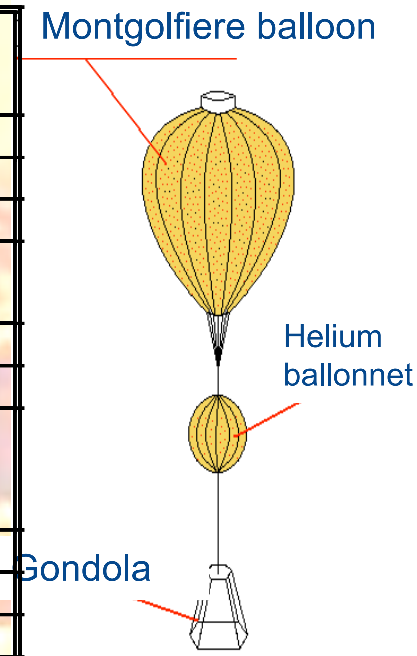


from Jonathan Lunine et al., "Titan Planetary Exploration Study," JPL Final Report, Pasadena, CA, May 2006

The *in-situ* elements of TSSM (I)

Strawman payload for the Montgolfière

Instruments on the Montgolfière	Mass (Kg)	Power (W)
Core payload		
Stereo Camera (s) (VISTA-M)	2	6
Balloon imaging Spectrometer (BIS)	2.3	10
Atmospheric Structure Instrument/Meteorological package (ASI / MET)	1	5
Titan Electric Environment package (TEEP-B)	1	1
Montgolfiere Radio Science Transmitter (MRST)	1	TBD
Titan Montgolfiere Chemical Analyser (TMCA) options 1 or 2 (GCMS with Stable isotope measuring capabilities + ACP-like for sample analysis & aerosol analyser)	16 or 11	40 or 35
Titan Radar Sounder (TRS)	8-12	15-25
Magnetometer (MAG)	0.5	1.5
Core payload Total	**27+**	**73+**
Additional/replacement payload		
Titan Montgolfiere Chemical Analyser (TMCA 3 or 4)	11 or 5	35 or 25
Titan Altimeter and Lake Penetrating Radar (TALPR)	5-7	10-25
Spectropolarimeter for Planetary Exploration (SPEX)	<5	<3
Grand total	**42+**	**111+**



The *in-situ* elements of TSSM (I)

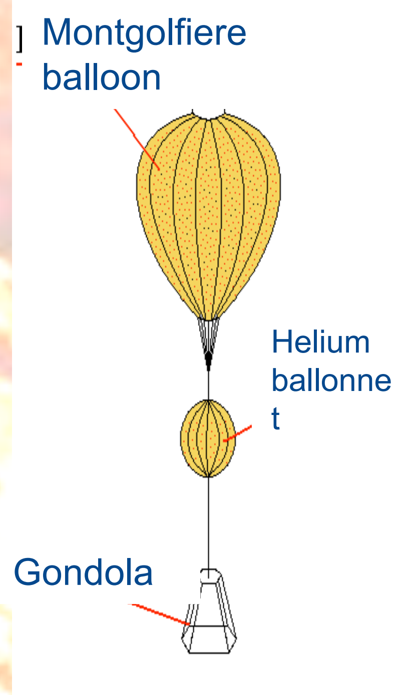
Table 1 Instrument interface summary for gondola core payload elements.

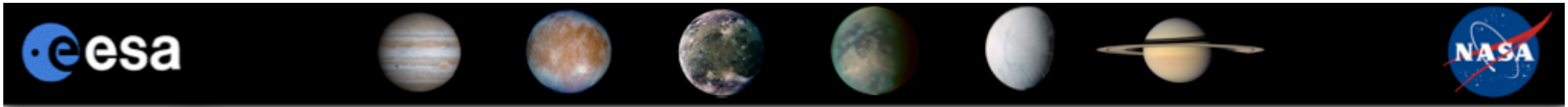
Instrument	*Acronym*	*Mass [kg]*	*Size [cm]*	*Power [W]*	*TM [kbps]*
Stereo Camera (s)	VISTA-M	2	TBD	6	TBD
Titan Montgolfiere Chemical Analyser (1 or 2)	TMCA(1 or 2)	16 or 11	50x40x20	40 or 35	5
Balloon Imaging Spectrometer	BIS	2.3 (1kg opt. head, 1.3 kg electronics)	26x24x15 (opt. head) 20x30x10 (electronics)	10	740
Atmosph. Structure Instrument /Meteorological Package	ASI/MET	~ 1	~20x20x20	~5	~0.150
Titan Electric Environment Package – Balloon	TEEP-B	0.3 – 0.95	Electroncs: 10×10×2 Plus antenna	1	TBD
Titan Radar Sounder	TRS	8 – 12	37x25x13	15-25	
Montgolfiere Radio Science Transmitter	MRST	1	TBD	TBD	TBD (very low)
Magnetometer (Option 1)	MAG	0.5	Each sensor: 11 x 7 x 5	1.5	0.8

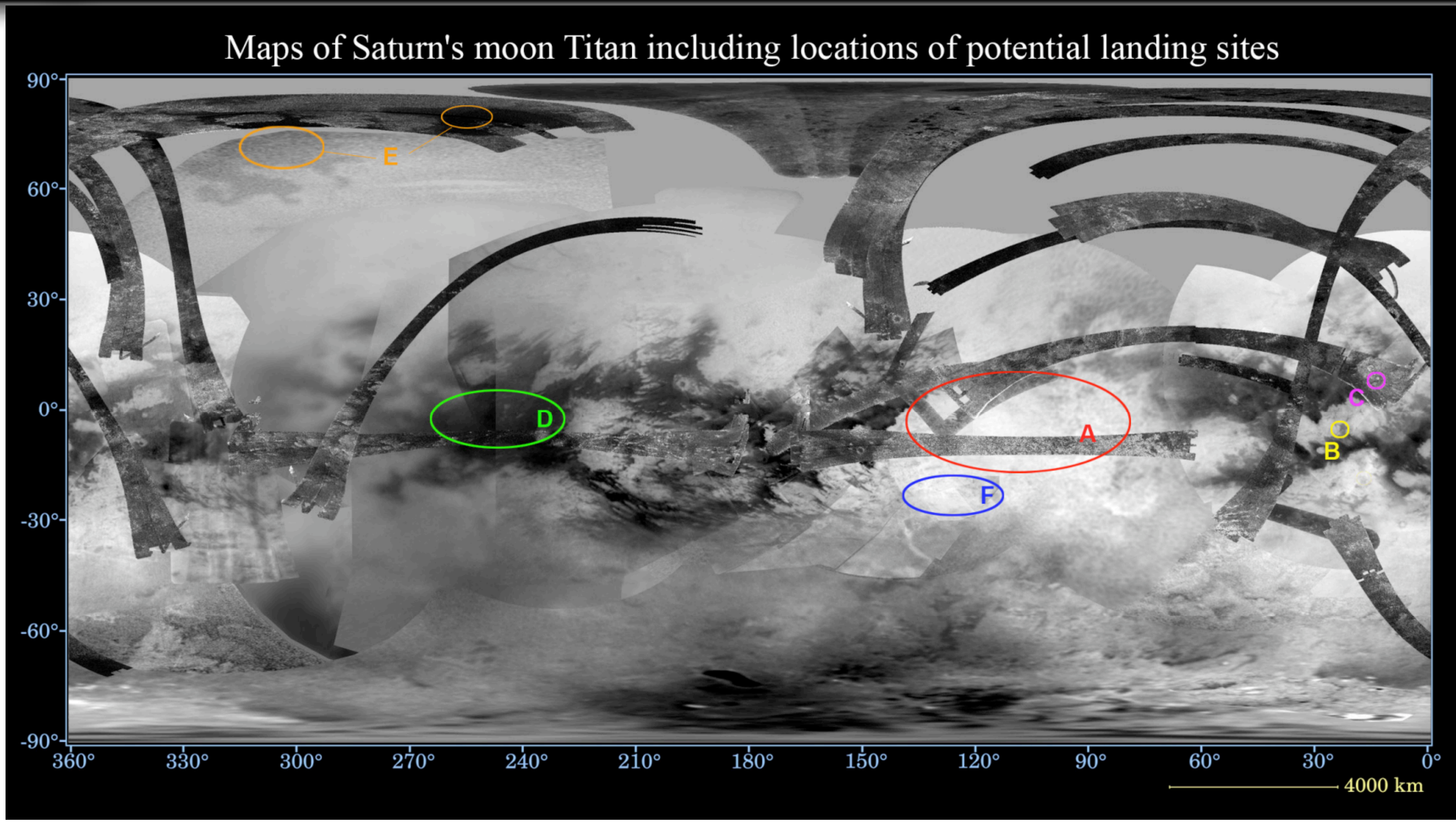
Table 2 Instrument interface summary for gondola replacement payload elements

Instrument	*Acronym*	*Mass [kg]*	*Size [cm]*	*Power [W]*	*TM [kbps]*
Titan Montgolfiere Chemical Analyser (4)	TMCA(4)	5	35x25x15	25	5
Titan Altimeter and Lake Penetrating Radar	TALPR	5 – 7	30x30x30	10-25	
Nephelometer	SPEX	< 5 (tbc)	13x13x6	< 3 W (tbc)	10 (tbc)

Strawman payload for the Montgolfière

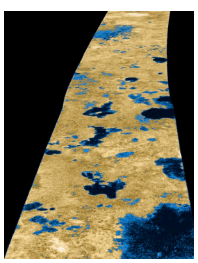






First order targets:

(D) Brownish **dune units e.g. Belet dunefield** (can be hit by 15x40° ellipse (600x1600km)); coordinates: 255°W 5°S (center of ellipse) see also appendix
Reason: fits most of engineering requirements and addresses most science objectives



(E) **North Polar Lakes** above 65°N (200km circular delivery error can be accomodated in LigeiaMare; Kraken Mare can probably accommodate ~400km circular delivery zone) coordinates: > 72°
Reason: fits the most exciting science goals of the methanological cycle and productions of organics

The *in-situ* elements of TSSM (II)

Strawman payload on the probes/landers

Probe/lander **Long-lived targeted to dry land**	**Mass (Kg)**	**Power (W)**
Core payload		
Visible radiometer & NIR cameras and spectrometer (TIPIRS)	4.9	24/44
Titan Lander Chemical Analyser (TLCA) option 4	5	25
Seismometer (SETI)	1	0.1
Lander Radio Science Transponder (LRST)	2	20
Atmospheric Structure Instrument / Meteorological package (ASI / MET)	1	5
2 Microphones	0.5	0.8
Atmosphere electricity sensor (TEEP-L)	0.5	0.5
Microscope / close-up imager (MCI)	0.3	<5.5
Titan Regoltih Subsurface Mole for Physical Properties (TiReS)	1.7	10
Magnetometer (MAG-L)	03	0.6
Core payload Total	**17+**	**63+**
Additional/replacement payload		
Raman SpEctrometer for Titan Remote Observation (RETRO)	2.1	<10
Icy mineralogy Package (XRF / XRD combined) (IMP)	0.5	12
Sub-critical water extractor & μ-Capillary Electrophoresis (μCE)	3.8	20
Grand total	**23+**	**98+**

Probe/lander 2 **Short-lived targeted to lake**	**Mass (Kg)**	**Power (W)**
Core payload		
Visible radiometer & NIR cameras and spectrometer	4.9	24/44
Titan Lander Chemical Analyser (TLCA, option 4)	5	25
Lander Radio Science Transponder (LRST)	2	20
Atmospheric Structure Instrument / Meteorological package (ASI / MET)	1	~5
Titan Electric Environment Package – Lander (TEEP-L)	0.5	0.5
Acoustic Sensor Package (ACU)	0.25	0.8
Magnetometer (MAG-L)	0.3	0.6
Core payload Total	**14+**	**76+**
Additional/replacement payload		
Microprobe mass spectrometer (Mini-MS)	0.3	2
Raman SpEctrometer for Titan Remote Observation (RETRO)	2.1	<10
Grand total	**16+**	**88+**

The *in-situ* elements of TSSM (II)

Preliminary strawman payload on probe/lander 1, long-lived, dry landing

Table 1 Instrument interface summary for lander 1 core payload elements.

Instrument	*Acronym*	*Mass [kg]*	*Size [cm]*	*Power [W]*	*TM [kbps]*
Titan Lander Chemical Analyser (4)	TLCA(4)	5	35x25x15	25	5
Lander Radio Science Transponder	LRST	2	TBD	20 (TBC)	TBD (very low)
Titan Probe Imager Radiometer Spectrometer	TIPIRS	4.9	20x20x10 for the spectrometer	24 (44)	10
Titan Regolith Subsurface Mole for Physical Properties	TiReS	1.7	35x35x12	17	30 Mbits;
Titan Electric Environment Package – Lander	TEEP-L	0.5	10 (electronics) ([1])	0.5	TBD
Acoustic Sensor Package	ACU	0.50	TBD	0.8	1kbps
Atmospheric Structure Instrument /Meteorological Package	ASI/MET	~ 1	~20x20x20	~5	~0.150
Magnetometer (Option 2)	MAG	0.3	Each sensor: 11 x 7 x 5	0.6	
Microscopic/close-up imager	MCI	0.3 (w/o DPU)	5x5x10	<5.5 (tbc)	tbd
Seismometer	SETI	1.1	9x9x9 (sensor) 10x15x5 (electronics)	0.1	2 Mbits/day

Table 2 Instrument interface summary for lander 1 replacement payload elements

Instrument	*Acronym*	*Mass [kg]*	*Size [cm]*	*Power [W]*	*TM [kbps]*
Icy Mineralogy Package (XRD/XRF) - reflection version	IMP-reflection	0.150 kg	500 cm^3	4.8 W	min 3.6 kb per sample
Icy Mineralogy Package (XRD/XRF) - transmission version	IMP-transmission	0.270 kg	900 cm^3	7.2 W	min 3.6 kb per sample
Raman Spectrometer for Titan Remote Observation	RETRO	2.1	- Spectrometer: 15x15x10	<10	1,024 (in a nominal scenario)
Sub critical water extractor & capillary eletrophoresis	tbd	tbd	tbd	tbd	TBD

The *in-situ* elements of TSSM (II)

Preliminary strawman payload on probe/lander 2, short-lived, wet landing

Table 1 Instrument interface summary for lander 1 core payload elements.

Instrument	*Acronym*	*Mass [kg]*	*Size [cm]*	*Power [W]*	*TM [kbps]*
Titan Lander Chemical Analyser (4)	TLCA(4)	5	35x25x15	25	5
Lander Radio Science Transponder	LRST	2	TBD	20 (TBC)	TBD (very low)
Titan Probe Imager Radiometer Spectrometer	TIPIRS	4.9	20x20x10 for the spectrometer	24 (44)	10
Titan Electric Environment Package – Lander	TEEP-L	0.5	10 (electronics)	0.5	TBD
Acoustic Sensor Package	ACU	0.50	TBD	0.8	1kbps
Atmospheric Structure Instrument /Meteorological Package	ASI/MET	~ 1	~20x20x20	~5	~0.150
Magnetometer (Option 2)	MAG	0.3	Each sensor: 11 x 7 x 5	0.6	

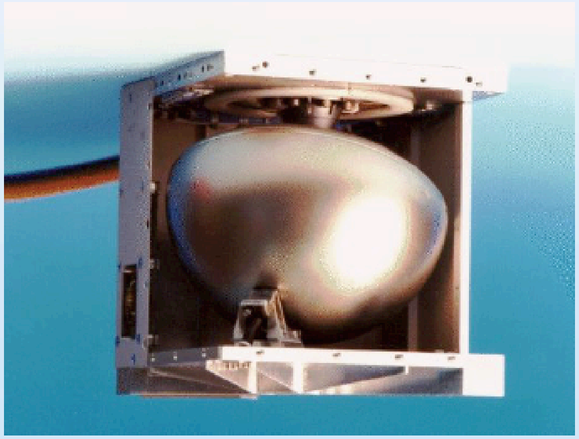
Table 2 Instrument interface summary for lander 1 replacement payload elements

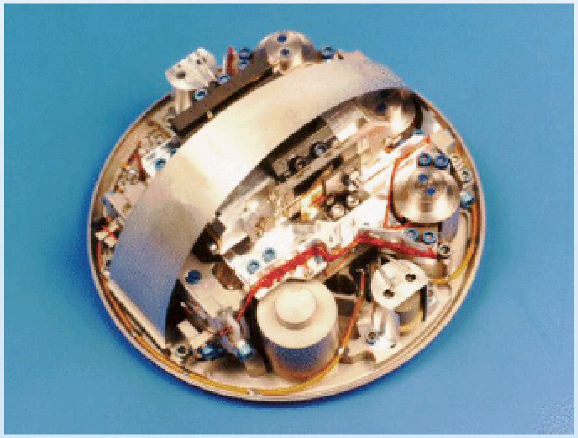
Instrument	*Acronym*	*Mass [kg]*	*Size [cm]*	*Power [W]*	*TM [kbps]*
Microprobe Mass Spectrometer	Mini-MS	0.3	3x3x10	2	5
Raman Spectrometer for Titan Remote Observation	RETRO	2.1	- Spectrometer: 15x15x10	<10	1,024 (in a nominal scenario)

Exploring Titan's subsurface with a seismometer (or two…)

OPTIMISM/Hardware

- Vertical seismometer with internal leveling system
  - ~ 450 g for the sensor / 450 g for the electronics / 1000 g total mass
  - Instrument mounted on the lander structure
  - IPGP design and SODERN manufacturing
  - Titan case: larger seismic proof mass (lower gravity) + feedback electronics + thermal protection (250 gr extra mass)





Exploring Titan's surface for astrobiology: protocol of the analysis of organic samples

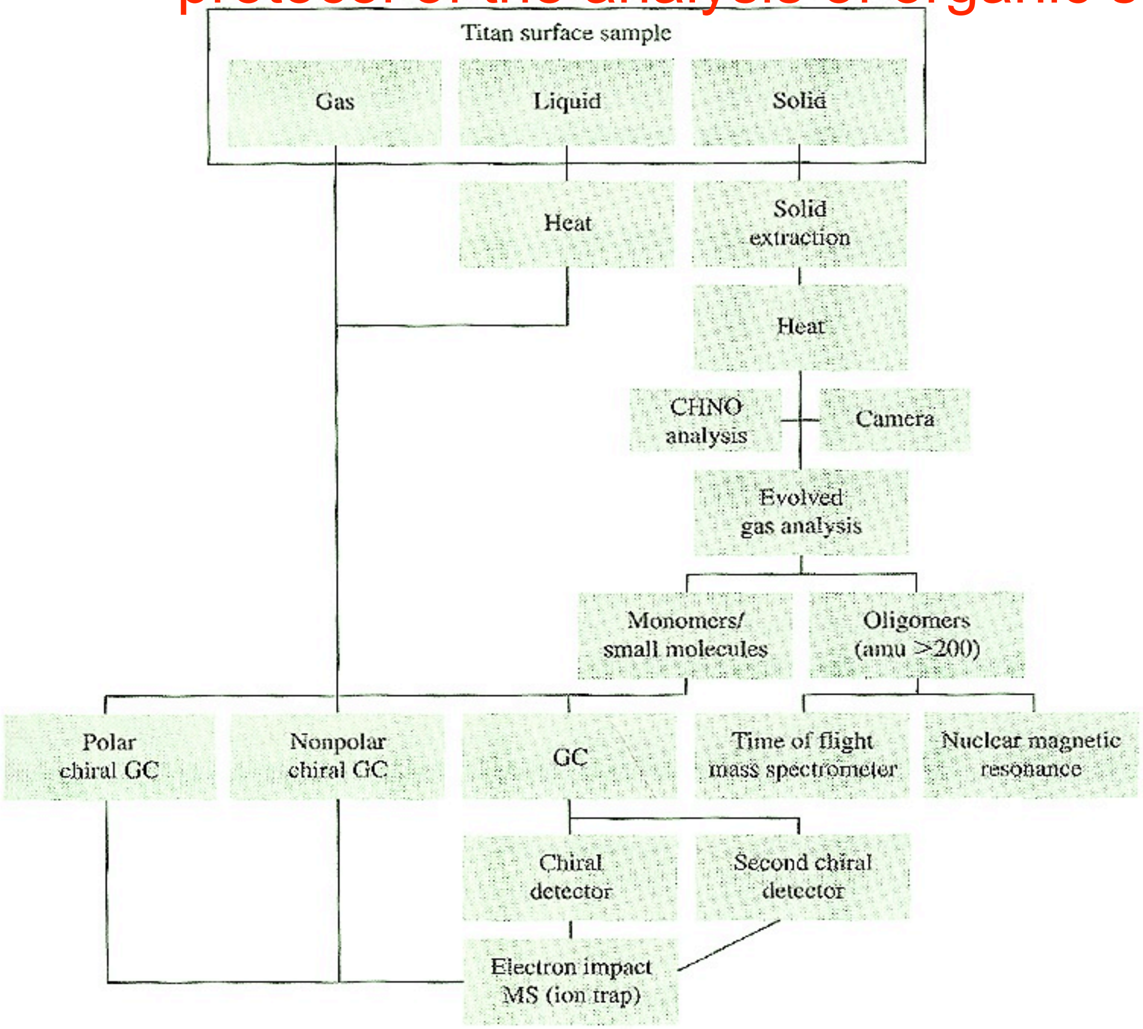


FIGURE 14.12 Protocol for the analysis of organic samples in the surface of Titan, progressing from simple elemental analyses to determination of enantiomeric composition and polymeric structure.

J. Lunine : Astrobiology

TSSM in situ will

go for killer science, not incremental science!

- Focus on surface-subsurface

by

- Imaging (vis-ir-radar) from aerial platform (balloon/aerobots)
- Having a laboratory on aerial platform
- Studying the context (essential !): meteorology, atmospheric composition, pressure-temperature

Key technology study areas

-Improve upon Huygens EDL technology
-Extend to controlled dips for aerocapture
-Technology development for balloons, mini-probes & penetrators
-DtE communications
-RTG heat exchanger, material development (2-layer concept) and drop & deployment test for Montgolfière balloon. Small RTGs enable many new options (small balloons, long-lived seismic stations etc)
-Microelectronics development which can be done under low radiation specification for mission.
-Develop tether system and surface sampling capabilities.
-Trade studies on solar electric propulsion
-Trajectory designs for probe/landers/ penetrators releases on Titan and Enceladus
-On-board science autonomy: data selection, compression and storage
C&DH and Telecom systems

The new Titan/Saturn System Mission (TSSM)

TandEM was selected for further studies of a future Outer Planet Mission to be chosen among TandEM and Laplace (Europa-Jupiter System Mission)
NASA selected Titan Explorer for further studies of an OPM vs Europa Explorer and Jupiter System Orbiter

Hence : Titan/Saturn System Mission !
Aiming for launch in 2017-2018

The studies of TSSM are conducted in collaboration between ESA-NASA (and other possible agencies).

The cost will be defined after studies but in the range of a Cassini-Huygens mission (NASA: 2.1 $B, ESA : up to 650 M€).

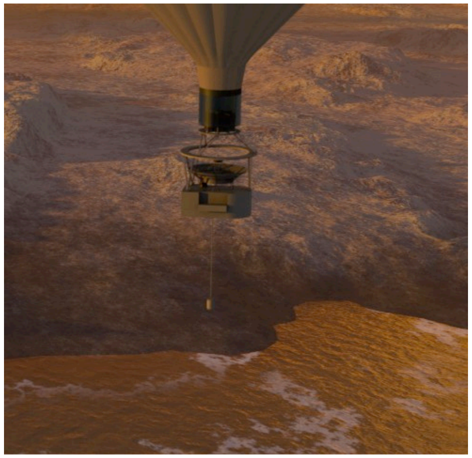
The current mission responsibilities are

NASA - the orbiter

ESA - the in situ elements for Titan exploration

Outreach

-Cassini images of the Saturnian system have been Astronomy picture of the day regularly several times in sequence…
-The press adores this kind of adventures: Scientific American, in its October issue, has a beautiful picture of a Titan Balloon, part of an issue on the future of Space Exploration: *http://www.sciam.com/issue.cfm*
-The general public loves the exploration of new places and in particular when they bear a relation to life and habitability
-Titan/Huygens is the farthest away we have landed on so far and it has ignited the imagination of the public. Exploring this new world in depth and in situ will be like revealing a new land to the world and bringing a new continent on the map.
-We have no doubt that the public in general and many informed people will follow this mission and its results with great interest
-TSSM will have an immense impact on everyone!



Extract from Scientific American , Oct. 2007